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Sanitary Conservation of Water Resources

Stresses in Composite Structural Members

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JOURNAL OF THE

BOSTON SOCIETY OF CIVIL ENGINEERS

Volume XIII FEBRUARY, 1926 Number 2

SOME EFFECTS OF "CAL" ON CEMENT AND CONCRETE

BY MILES N. CLAIR,* MEMBER, BOSTON SOCIETY OF CIVIL ENGINEERS

(Presented before the Designers Section, B. S. C. E., on January 13, 1926)

THE increase in winter construction and the increasing amount of concrete work where traffic has to be dealt with have led to considerable use in recent years of substances for accelerating the hardening of Portland cement concrete. Of these admixtures, those depending on the effect of calcium chloride have been shown by use to be most effective, and considerable data as to their action have accumulated. The information available, however, does not include the effect of the accelerators on certain properties of cement and concrete under subnormal temperature conditions, such as occur in the important field of winter construction.

A series of investigations was undertaken at Drexel Institute, Philadelphia, under the direction of Lewis R. Ferguson † and the author ‡ to determine the effect of Cal, which is a commercial form of calcium oxychloride, on certain of those properties of neat cement, cement mortar and concrete which act as limitations in the use of these materials, especially at the lower temperatures. These investigations extended from February to July, 1925, and involved approximately 150 "time of set" determinations; about 3,000 "tension" tests; 32 "modulus of elasticity" tests; and 100 "compression" tests. Specimens were stored at temperatures of 32° F., 43° F., 55° F. and 70° F., and tested at various ages. Admixtures of 3, 5 and 8 per cent Cal were used. The results of the investigation gives information as to the effect of Cal on the following:

---

* Testing Engineer, The Thompson & Lichtner Company, Inc., Boston, Mass.

† President, Light, Hollister & Ferguson, Consulting Engineers.

‡ In charge of the Strength of Materials Laboratory, Drexel Institute, Philadelphia.

(1) Time of set of cement.
(2) Strength of neat cement in tension.
(3) Strength of cement mortar in tension.
(4) Strength of concrete in compression.
(5) Elastic properties of concrete.

General Procedure

The specifications of the American Society of Testing Materials were followed in so far as they applied, and every effort was made to keep the conditions uniform. All specimens were made in the strength of Materials Laboratory of Drexel Institute except those of the machine-mixed concrete, which were made in the East Yard of that school. All material was weighed and the cement and Cal were screened through a 30-mesh sieve before using. The program of tests was so arranged as to distribute the making and breaking of a given series of specimens over a number of days, with the object of reducing the effect of special conditions prevailing on any one day.

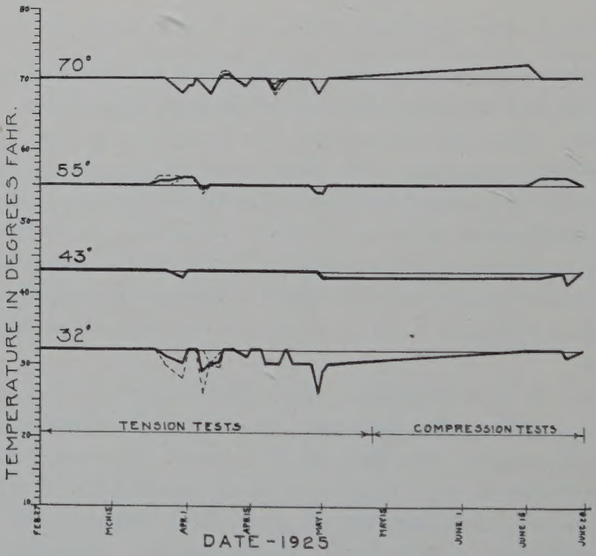

Fig. 1. — Storage Temperatures (Average Daily)

Storage.

The storage rooms were selected from a number available because they remained at a more nearly constant temperature, as shown by trial temperature observations. The 32° F. storage room was the ice-storage room of an ice-cream plant; the 43° F. room was the "casing" storage room of a beef-butchering plant; the 55° F. room was the "oleo" storage room of the same beef-butchering plant; and the 70° F. room was the Testing Materials Laboratory of Drexel Institute. The storage rooms were all approximately 50 by 100 feet in plan and the subnormal temperature rooms were within two squares of the laboratory. The walls and floor of the low-temperature rooms were continuously wet, indicating humidity conditions near 100 per cent. The specimens in the laboratory were kept under wet burlap bags.

The maximum and minimum temperatures in the storage rooms were read daily and the variations are shown on Fig. 1. "Sixes" maximum and minimum thermometers were used to determine the temperatures. These thermometers have two tubes so arranged that when the temperature rises one leg of the mercury column rises and the other falls. A small metal slug in the tube is forced along by the mercury and remains at the maximum position when the mercury recedes again. The slugs are reset by means of a small magnet.

Materials

All materials used in these tests were standard products obtained in the local market. Standard brands of Portland cement were selected so as to include fast, medium and slow setting types, and one foreign brand. These cements all passed the standard tests, the results of which are given in Table No. 1.

TABLE NO. 1. — RESULTS OF STANDARD TESTS OF THE CEMENTS USED

CEMENT	Per Cent retained on 200 Sieve	Normal Consistency	TIME OF SET				Soundness	TENSILE STRENGTH, AVERAGE OF 3 BRIQUETTES	
			Initial		Final			7-day	28-day
			Hrs.	Mins.	Hrs.	Mins.			
Atlas*	18.8	24.4	3	10	4	10	O. K.	290	365
Lehigh*	–	22.6	2	30	4	20	O. K.	213	343
Bath*	18.4	23.6	4	30	6	0	O. K.	267	385
Security*	15.4	24.4	2	55	4	25	O. K.	293	433
Vulcanite*	–	22.6	3	28	4	48	O. K.	248	367
Mons.†	–	22.4	2	33	4	55	O. K.	258	393

* Furnished by E. M. Smith & Co., Philadelphia.

† Furnished by Philadelphia Importing Company, Philadelphia.

Cal. — The Cal used in these tests was a commercial Cal which contained about 20 per cent calcium chloride. Cal is oxychloride of calcium which is made by hydrating lime with a solution of calcium chloride and then grinding the resultant mass so as to have about 85 per cent passing a 100-mesh sieve. It reacts readily with water to form calcium hydroxide and calcium chloride, and is, therefore, equivalent to adding hydrated lime and calcium chloride to concrete. This means increased set and workability due to calcium chloride and increased workability and decreased permeability due to the hydrate. Cal in its commercial form is a dry, white powder that does not deliquesce like calcium chloride and long exposure does not affect its action as an accelerator. It is used dry with the cement and aggregate. Technologic Paper No. 174 of the United States Bureau of Standards and Bulletin No. 13 of the Structural Materials Research Laboratory give the results of comprehensive tests of the effect of Cal on concrete.

Sand and Gravel. — The sand and gravel were of clean, hard material and had the following characteristics: —

Sand — no organic matter; good grading; fineness modulus 2.35.
Gravel — some flat stones; lacking in fine material; fineness modulus 6.00.

Water. — City water was used, and its temperature, as well as that of the other materials, was brought to the laboratory temperature before being used.

TIME OF SET TESTS

The effect of Cal on the time of set of neat cement was thought to give an indication of the effect of Cal on the time of set of concrete, and as the setting time is of particular importance at lower temperatures, this series of tests was designed to give information for temperatures of 70° F., 55° F., 43° F., and 32° F. The six cements shown in Table No. 1 were used, and, in addition, a blend made of equal weights of each of the six cements. The water required for normal consistency was determined at 70° F. laboratory conditions for each of these cements plain and with the addition of Cal to the amount of 3, 5 and 8 per cent of the weight of the cement. Normal consistency for the cement with Cal is based on the ratio of the weight of water to the weight of the cement alone.

Test Methods

The time of set was determined by means of the Vicat apparatus. Rings were molded at 70° F. in the laboratory and were placed at once in a container packed in ice. The temperature in the container was checked by a thermometer and regulated to approximate the storage temperature. Within about fifteen minutes the container and specimens were removed to the particular storage room. The temperature in the storage rooms remained absolutely constant during the period of these tests. Some doubt arose as to whether or not the specimens at 32° F. were frozen, and therefore all of these were removed to 70° F. after final set had apparently occurred. In no case was there indication of freezing.

TABLE NO. 2.—WATER REQUIRED FOR NORMAL CONSISTENCY

CEMENT	PER CENT OF CAL			
	0	3	5	8
Atlas	24.4	25.3	26.3	27.0
Lehigh	22.6	23.6	25.0	26.0
Bath	23.6	24.0	25.0	26.6
Security	24.4	24.0	25.4	27.0
Vulcanite	22.6	24.2	25.6	27.2
Mons	22.4	23.8	25.0	26.2
Combination of all	22.2	23.4	25.0	26.6
Combination of Atlas, Bath and Security	23.8	–	25.2	26.4

NOTE: — Normal consistency is based on ratio of weight of water to weight of cement alone.

Data and Curves

The results of the time of set tests, shown on Fig. 2, were all observed data or plotted. The regularity of the final set results makes it permissible to plot curves, but the initial sets were erratic, and therefore the points are joined by straight lines. Table No. 2 is a tabulation of the water required for normal consistency.

Conclusions

The data and curves for the final set indicate that the effect of Cal admixture up to 8 per cent by weight of the cement is in general the same for all the cements used in that —

(1) Increase of Cal produces decreased time of set.
(2) The addition of 8 per cent of Cal causes the time of set at 32° F. to be about the same as at 70° F. using plain cement.
(3) Cal does not produce a flash set.
(4) Cal does not cause a retarding action.
(5) The effect of Cal increases as the temperature decreases.

The data show, further, that the cement does set at 32° with or without Cal; that the time of set is greater the lower the temperature and about proportional to the change in temperature; and that 8 per cent Cal practically eliminates the difference in the time of set between the various cements.

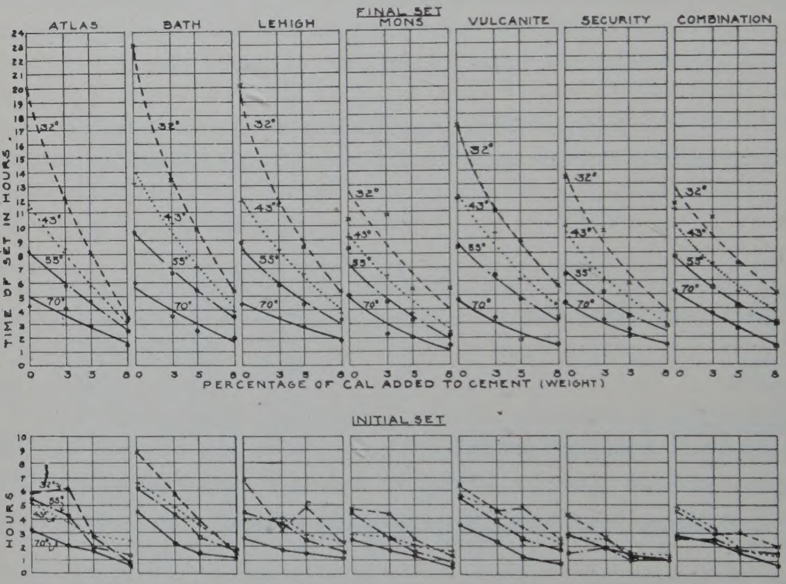

Fig. 2. — Effect of Cal on Time of Set of Cement at Various Temperatures (Vicat Method)

The initial set results, although somewhat erratic, follow in a general way the results of the final set test, except that there is very little difference in the time required at the several temperatures. The initial set results were undoubtedly affected greatly by the initial temperature conditions although every effort was made to keep these constant.

The normal consistency results indicate that the addition of Cal to neat cement requires an increase of water over that which would be required for the addition of the same amount of cement. This agrees with Bulletin No. 13 of the Structural Materials Research Laboratory, but disagrees with Technologic Paper No. 174 of the United States Bureau of Standards. However, Technologic Paper No. 174 does check closely the effect of Cal on the time of set. There was a very decided difference noticeable in the working of cement with and without Cal. The addition of Cal causes the cement to become fat or slippery, with the appearance of increased fluidity. This increased fluidity is not the same as the property called "consistency," but is rather an increased workability due to the lubricating effect of Cal.

NEAT CEMENT TENSION TESTS

This series of tests was designed to show the effect of various percentages of Cal on the tensile strength of cement at subnormal temperatures. Although such tests are not of direct application to concrete, they do indicate whether or not Cal has a detrimental effect on the cement itself. The effect of initial temperature conditions was considered important, and therefore a group of specimens designated as "A" was made which were removed at once to the storage room. An exactly parallel group, designated as "B", was allowed to remain five hours in a moist closet at 70° before removal to the storage room. Group "A" consisted of three standard briquettes each of neat cement, 5 and 8 per cent Cal, stored at 70°, 55°, 43° and 32° and tested at, 1, 2, 3, 4, 7, 14, 21 and 28 days. Group "B" consisted of an exactly parallel series, excluding, of course, the 70°. The cements used for these tests were selected from the results of the time of set tests; one fast (Security), one slow (Bath) and one medium (Atlas) time of set cement were used, and, in addition, a blend of equal parts of all three.

Procedure

The specimens were molded in standard brass gang molds at laboratory temperature, using the normal consistency as determined by the previous tests. The method of molding was the standard method described by the A. S. T. M., and the specimens, after being molded, were removed to the storage rooms at once, or in five hours, according to the series to which they belonged. The day after being made, the specimens were removed from the molds and were then not disturbed until the day of test. On the day that the briquettes were to be tested, they were removed to the laboratory, allowed time to come to the laboratory temperature and then tested in a standard Olsen Testing Machine, Shot Type.

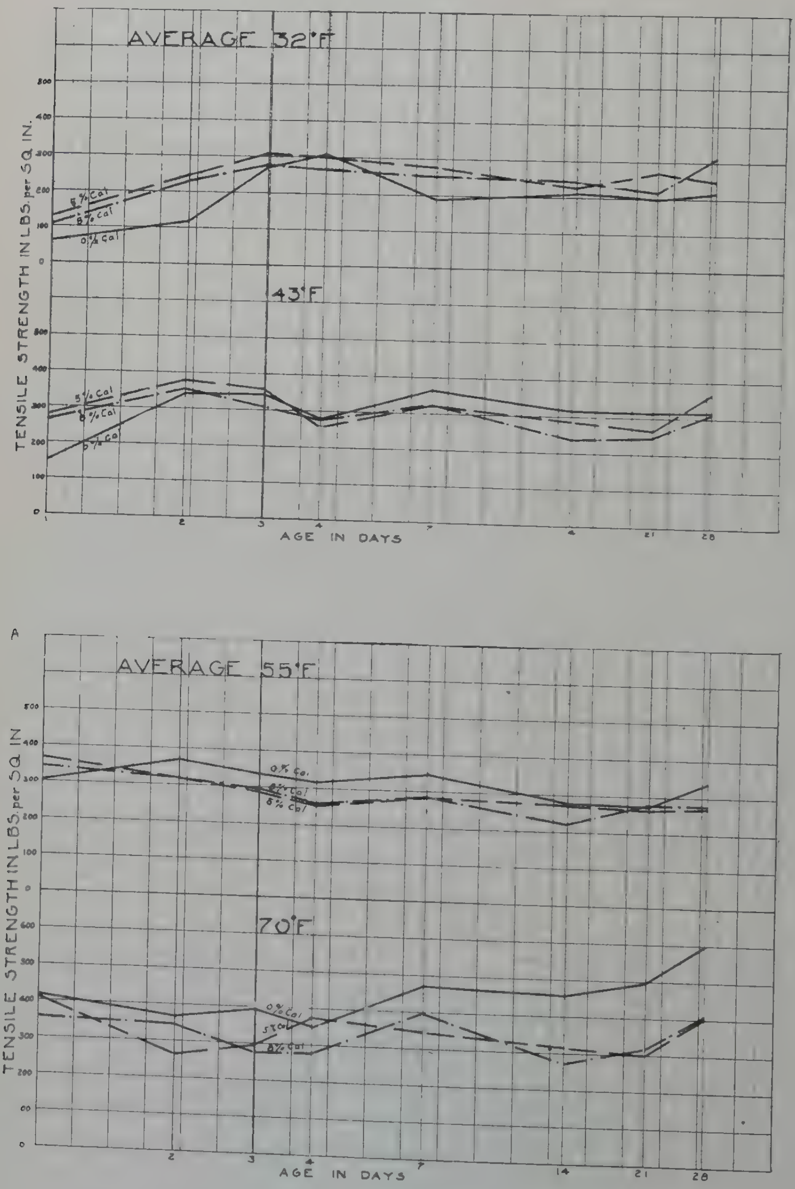

Fig. 3. — Neat Cement Tests — Series A

Data and Conclusions

The breaks obtained in the tension tests showed considerable variation. The fractured surfaces were similar for the plain and Cal specimens, except for the 32° storage, where the plain specimens showed a peculiar plane of fracture. This type of fracture was similar to the planes of cleavage peculiar to the fractured surface of slate or shale. It is thought that a study of this peculiar fracture may throw further light on the action of hardening of cement. In some cases the surfaces of the 8 per cent Cal specimens showed white particles; these may have been unmixed Cal or precipitated lime. The manipulation of the material makes the latter more probable.

Figs. 3 and 4 give the results obtained by averaging the four cements. The abscissa has been plotted to a logarithmic scale in order to more clearly indicate the data. Despite the extreme care taken to keep conditions uniform these curves are erratic, showing small difference in the strengths with and without Cal up to the percentage used. The curves for the individual cements are similar to the average curves. The curves do indicate, however, that up to the percentages used Cal

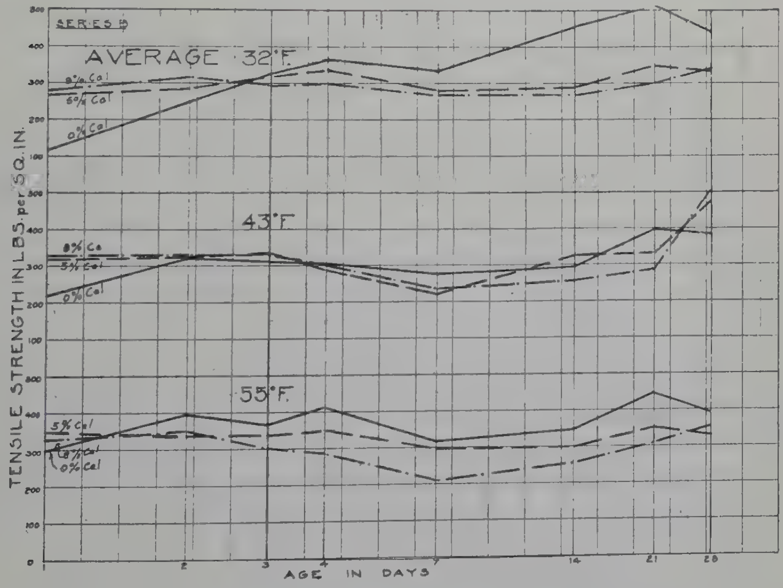

FIG. 4. — NEAT CEMENT TESTS — SERIES B

does not have a particularly injurious effect on the action of cement at the ages and temperatures investigated, except for 70° F. The data and curves do not show two important effects of Cal which were very apparent in the actual molding and testing of the specimens. These effects are (1) the fattening effect of Cal, making for ease in molding, and (2) the greatly increased stiffening or setting effect. The latter effect was shown by the fact that at lower temperatures the Cal specimens could always be removed from their molds the day following molding, while the plain cement briquettes could not be removed until several days later. There was no difficulty in distinguishing between the plain and the Cal specimens due to this difference in set at any temperature used. The "B" series curves indicate an increase in strength due to the initial curing period at the higher temperature, but otherwise the curves are similar to those of the "A" series.

MORTAR TENSION TESTS

Scope and Methods

A short series of specimens was prepared to show the effect of Cal on the tensile strength of mortar at normal temperature and to show the effect due to changing the water-cement ratio when Cal is used. A mixture of 1 part of the combination cement used for the neat tension test, and 3 parts by weight of the sand used for the concrete tests, was employed for the briquettes. Three sets of briquettes were made: one contained no Cal and was of normal consistency; one contained 5 per cent Cal (by weight of cement) and the same amount of water as for the plain mortar; and the third set contained the same amount of ingredients as the second, except that sufficient water was added to give normal consistency. Six briquettes of each set were made for test at 2, 4 and 7 days. The molds were stripped at the end of twenty-four hours and the specimens allowed to remain in the air of the laboratory until tested.

Data and Discussion

The data for these tests are shown plotted on Fig. 5. The regularity of the curves and the similarity to the compression curves, given at a later point in this paper, are to be noted. The Cal specimens show an increase in strength over the plain mortar for all ages tested. The Cal specimens, with the same water-cement ratio as the plain briquettes, showed a greater strength, while the 5 per cent Cal specimens with increased water a somewhat lower strength, and the plain specimens the lowest of all. The fattening effect of Cal, similar to its effect on the neat cement, was decidedly noticeable during the manipulation of the material.

Attention is called to the fact that in the neat tension briquettes sufficient water was added in all cases to give normal consistency as determined by the Vicat apparatus. This meant an increased water-cement ratio for the Cal specimens. Considering the results of the mortar tests, it would seem that if the water-cement ratio had been kept constant, much higher strengths would have been obtained for the Cal neat tension tests than for the plain neat tension tests.

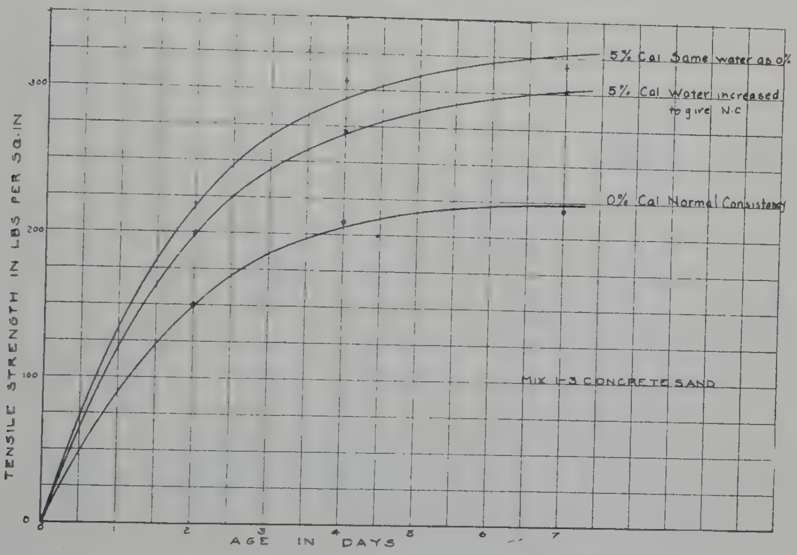

FIG. 5. — MORTAR TENSION TESTS

COMPRESSION TESTS

The tension tests indicate the action of Cal on neat cement, but the action of Cal on concrete is not necessarily analagous. The addition of Cal to neat cement causes a displacement of cementitious material by one of much lower strength-gaining qualities, and therefore the true effect of Cal is not apparent. When Cal is added to concrete, however, the true accelerating action on the strength of the cement is available. There is also a further increase in strength of the concrete due to the lubricating action of the Cal, which causes the inert materials to form a more uniform and denser mixture. This series of tests has as its object the determination of the effect of Cal on the compressive strength of concrete at various temperatures and ages.

Procedure

Three specimens of plain cement and three with an addition of Cal to the amount of 5 per cent by weight of the cement were made for ages of 4, 7, 14 and 28 days and temperatures of storage of 70°, 55°, 43° and 32°. Two cylinders 3 by 6 inches, and one 6 by 12 inches, were used for each case, the latter serving also for the stress-strain determinations. The small 3 by 6 inch cylinders were used because of the difficulty of moving the larger cylinders to the various storage rooms.

The 3-inch diameter cylinders made it necessary to use a small aggregate, and therefore a ¾-inch gravel was selected as the limiting size. The properties of this gravel and of the sand used are given elsewhere in the paper. The blend of three cements used in the tension test was also employed for these tests. Several mixes were tried of varying proportions in order to obtain a workable mixture, and it was finally decided to use a 1: 2½: 3¾ field mixture, which approaches the usual 1:6 mix. The mixture was somewhat high in sand, but this was necessary due to the absence of fine material in the gravel. The true mix for the given field mix was also determined in order that a comparison might be made with the results of other work on the basis of Professor Abrams' method.

All material was weighed and then placed in separate containers and removed at once to the concrete mixer in the East Yard, about 50 feet away. This mixer was of the drum-tilting type and of a capacity of about four cubic feet. It made fifteen revolutions per minute and was gasoline engine driven. The aggregates and water were first introduced into the mixer and then the cement (and Cal when used). At the end of one and a half minutes of mixing, the concrete was dumped upon a sheet-iron plate and the slump determined. A slump of 6 inches was used for these tests, the same amount of water giving the same slump for both the plain concrete and the concrete containing 5 per cent Cal. The slump was determined several times during the filling of the molds. The size of the batch used was generally about half the capacity of the mixer.

The temperature at which the molding of the specimens took place varied between 75° and 85°, but the molds were not at this temperature more than twenty minutes. The forms were stripped from the specimens after twenty-four hours, except in the case of the plain concrete specimens stored at 43° and 32°, for which a longer period was required. The specimens remained in the storage rooms until just before testing, when they were removed to the laboratory and allowed to attain the normal temperature. The weight and dimensions were noted and then the cylinders were capped with plaster of paris. All the 3 by 6 inch cylinders were broken in a 30,000 pound Olsen Testing Machine and all the 6 by 12 inch cylinders were broken in a 200,000 pound Olsen Testing Machine. A spherical bearing block was used in both machines and the load was applied at 0.05 inch per minute.

Results and Conclusions

It was observed that all the breaks in compression were similar, showing the formation of a sloping crack and sudden failure, and in most cases giving partial cones. The specimens containing Cal in all cases showed better surfaces than the plain concrete. The plain concrete specimens at 32° developed blisters on the surface after removal from the storage room to the laboratory. No such disintegration was found in the Cal specimens. The peculiar planes of fracture observed in the 32° neat tension tests were also present in the 32° plain concrete compression tests.

The same slump was obtained for the 5 per cent Cal concrete as for the plain concrete, using the same water-cement ratio. The mixture containing Cal, however, looked appreciably richer and was much more easily manipulated. The same effect is noted in Technologic Paper No. 174. There was considerable separation of stone in the plain concrete a short time after dumping from the mixer, but the Cal concrete showed no such segregation. This is an important property to be taken into consideration where concrete has to be chuted or wheeled a long distance. There is considerable need for a test to determine quantitatively workability and flowability in order that such qualities may be evaluated. The data concerning the concrete are given in Table No. 3, and the results of the compression tests are given by the curves plotted on Fig. 6.

TABLE No. 3.—CHARACTERISTICS OF THE CONCRETE

Water-cement ratio: 1.065
Slump: 6 inches
Field mixture: 1:2½:3¾
True mixture: 1:4.8
Fineness modulus of mixed aggregate: 4.58
Average weight of all plain concrete: 145.1 pounds per cubic feet.
Average weight of all 5 per cent Cal concrete: 142.3 pounds per cubic feet.

The curves on Fig. 6 show the average of the breaks and the average curves drawn through these points. The curves are all plotted on the same base in order to show the variation of compressive strength with temperature, as well as the effect of Cal. The results of these tests, as indicated by the curves, show that for the given materials, mixture and consistency, the addition of 5 per cent Cal, by weight of the cement, increases the strength in compression at all ages and temperatures. Technologic Paper No. 174 shows a similar increase for normal temperature at the early ages but no increase at the 28-day period. Bulletin No. 13 of the Structural Materials Research Laboratory shows for normal temperature strength increases at all ages up to 28 days, but a somewhat less increase for the later periods than is shown by Fig. 6.

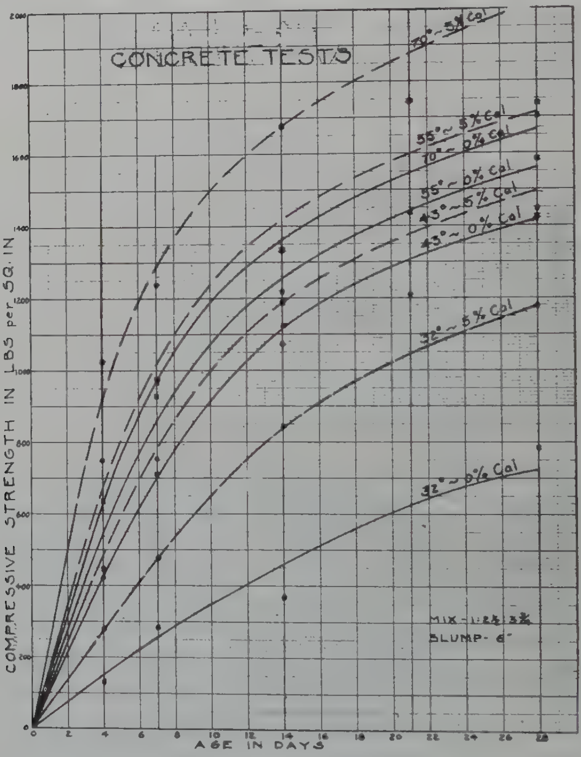

FIG. 6. — CONCRETE COMPRESSION TESTS

The study of these curves indicates that the effect of Cal is greatest for the 70° and 32° conditions, and that there is a diminution of effect regularly from 70° to 55° to 43°, and then an increase for 32°. No explanation has been found for the difference in effect of Cal on the strength at the several temperatures except that near 32° possibly a critical point is reached, due to the effect of calcium chloride on the freezing temperature of water. These curves indicate the possible saving in the time required before forms can be removed, since the age at which forms can be stripped depends on the stiffness and strength obtained by the concrete. The higher the strength required, the more the time ratio is in favor of the Cal concrete, and therefore the more the saving in favor of Cal.

Bulletin No. 81 of the Illinois Engineering Experiment Station, entitled "Influence of Temperature on the Strength of Concrete" agrees in general with the plain concrete curves of Fig. 6 — but shows more bunching near 70° and with the 32° strength curve somewhat lower. This bulletin further agrees with the results of these tests in that there is an increase of strength with age for all the temperatures, and that the rate of increase of strength decreases with the age of the specimen. Bulletin No. 81 deals with plain concrete only, but based on the data developed from the present investigation the conclusions appear to hold for concrete containing Cal as well as for plain concrete.

It is to be noted that Bulletin No. 13 of the Structural Materials Research Laboratory states that more water is required to obtain the same flow for Cal specimens than for the plain concrete, and Technologic Paper No. 174 states a slight increase is necessary. This seems to contradict the results of these tests, which show the same slump for the same water-cement ratio with or without Cal. However, the difference is probably due to the fact that the flow table was used for the other tests and the slump cone was used for work described in this paper.

The data on the weight of concrete with and without Cal indicate that the addition of 5 per cent Cal causes a decrease in weight of about 2 per cent.

MODULUS OF ELASTICITY

A knowledge of the elastic properties of concrete is essential in reinforced concrete design. The tests under this series are designed to give some information as to the effect of Cal on the elastic property of concrete, and consisted of the determination of the stress-strain curves for two concrete specimens at each of the ages of 4, 7, 14 and 28 days which had been stored at temperatures of 70°, 55°, 43° and 32°, one specimen being made with plain cement and the other with an addition of

5 per cent Cal based on the weight of the cement. The specimens used were 6 by 12 inch cylinders molded at the same time as the 3 by 6 inch compression cylinders, and employing the same materials, mix and slump. The 6 by 12 inch cylinders had cast in them two ⅜-inch diameter iron bars, 8 inches apart vertically, to be used for attaching the strain gages.

Procedure

The specimens were removed to the laboratory on the day of test and allowed to attain the laboratory temperature before testing. They were weighed, measured and capped with plaster of paris. Then punch marks were made in the two ⅜-inch iron bars, using a special 8-inch gage punch, and 1/16-inch diameter holes were drilled to receive the points of the extensometers. Specimens were placed in the 200,000 pound Olsen Testing Machine and carefully centered under the spherical bearing block, and then an initial load of 1,000 pounds was applied. If the gages were not working correctly, this load was released and adjustments were made.

The extensometers used in these tests were the Olsen "Last Word" strain gages, 8 inches between points, and reading direct to .00006 inch when used with 1/16-inch drilled holes. These gages are of the lever type, extremely sensitive and quickly attached. Two gages were used, attached to opposite sides of the specimen. The gages were held in position by a cord wrapped around them. Load was applied at 0.05 inch per minute and gage readings taken as the beam rose for given load increment.

Data and Conclusions

The data obtained from the tests, made to determine the effect of Cal on the elastic properties of concrete, are shown by the stress strain curves plotted on Fig. 7. Although the results of one determination of the stress strain curve for each case is not conclusive, a study of these curves would seem to indicate that concrete containing 5 per cent Cal in general has the same type of stress-strain curve as plain concrete. The initial tangent modulus is substantially the same for plain as for 5 per cent Cal concrete. The lower the temperature the flatter in general is the stress-strain curve. The data shows that the modulus of elasticity increases with age in the same general way as found in Bulletin No. 5 of the Structural Materials Research Laboratory.

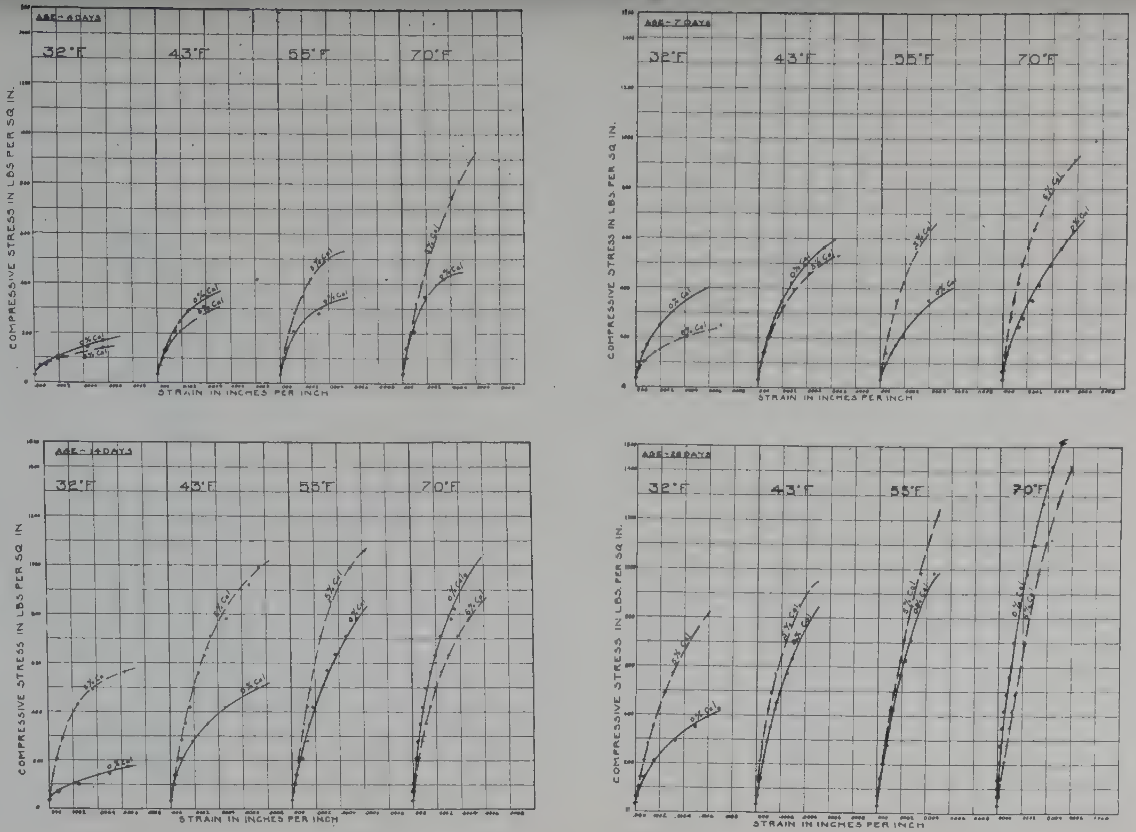

FIG. 7. — STRESS–STRAIN CURVES WITH 0% AND 5% CAL
Upper left — 4 days; upper right — 7 days
Lower left — 14 days; lower right — 28 days

Summary of Conclusions on Effects of "Cal"

Based on the study of the data from the tests described in this paper, the following conclusions have been drawn:

1. The addition of Cal decreases the time of set at all temperatures from 70° F. to 32° F.
2. As the amount of Cal is increased (up to 8 per cent at least) the time of set is progressively shortened.
3. The addition of 8 per cent of Cal causes the time of set at 32° F. to be about the same as plain cement at 70° F.
4. The addition of 8 per cent of Cal practically eliminates the difference in the time of set between various cements.
5. More water is required for normal consistency when Cal is added to neat cement.
6. Cal does not have any particularly injurious effect on the tensile strength of neat cement in quantities up to 8 per cent, at early ages.
7. The addition of 5 per cent of Cal to 1:3 mortar increases the strength at all ages tested.
8. The addition of Cal to 1:3 mortar as well as to neat cement makes it more easily manipulated.
9. The addition of 5 per cent of Cal to concrete of the character tested does not affect the slump.
10. The addition of Cal seems to lubricate the concrete, thus producing better molded surfaces and a greater density.
11. Cal prevents segregation.
12. For the concrete investigated, the addition of 5 per cent of Cal increases the strength of compression at all ages and temperatures.
13. Concrete containing 5 per cent of Cal has in general the same elastic properties as plain concrete.
14. The modulus of elasticity of concrete for a given age decreases with the temperature.

THE SANITARY CONSERVATION AND UTILIZATION OF WATER RESOURCES

By W. L. Stevenson*

(Presented before the Sanitary Section, B. S. C. E., on January 6, 1926)

Magnitude of the Problem in Pennsylvania

The Commonwealth of Pennsylvania includes about 45,000 square miles. Its topography is varied: the southeast quarter is a relatively flat, fertile plane, across the middle of the state extend the Allegheny Mountains, and west thereof the land is an elevated rugged plateau.

The main river systems of the state are: the Delaware, forming the boundary with New York and New Jersey; the Susquehanna, formed at Sunbury by the junction of the West and North Branches; and the Ohio, formed at Pittsburgh by the confluence of the Allegheny and the Monongahela.

There are at least 100,000 miles of named streams which, with an average rainfall of 48 inches a year, produce an aggregate average rate of flow of about 2,600,000,000 gallons an hour.

The 1920 census population was 8,720,017, divided as follows:

In cities over 100,000 population	2,657,689
In municipalities of 2,500 to 100,000 population	2,950,126
In communities under 2,500 population	2,170,842
On farms	941,360

The estimated 1925 population is 9,317,646

There are 973 incorporated municipalities, of which about one-half are sewered in whole or in part, and 210 sewage treatment works.

Six hundred and fifty public water-works supply about 6,500,000 people, or 70 per cent of the population, with water generally derived from surface sources.

Of these supplies, 170 are filtered and chlorinated and furnished to over 4,500,000 consumers; 258 only chlorinated, usually after storage, and furnished to about 1,750,000 consumers; and 222 either obtained from underground sources or from relatively uninhabited catchment areas, where watershed protection and storage are the safeguards, and these supplies are furnished to about 200,000 consumers.

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Many industries use large quantities of relatively clean waters in their processes of manufacture. It is estimated that there are at least 2,500 industrial places producing liquid waste-water which obviously must be discharged to the streams. These industries represent a capital investment of over $1,000,000,000 and their output is valued at over $1,500,000,000 a year.

When the white man first came to Pennsylvania, it was practically entirely covered with virgin forest. Development of the land made necessary the destruction of much thereof — most of the rest was used recklessly. Now the mountains and many of the hillsides are covered with second growth timber. There are probably over 13,000,000 acres of forest land in the state of which 1,131,000 acres are state forest lands. One-tenth of the state forest land serves as catchment area for water used by 250,000 people. Nearly 5'000,000 trees have been planted by water companies in the state for the purpose of stabilizing the rate of flow and improving the quality of their raw water.

Fishing is a popular recreation in Pennsylvania. During 1925 there were issued 251,000 fishing licenses. The Board of Fish Commissioners distributed this year from state hatcheries 326,000,000 fish having a commercial value of $350,000.

As in most other states the automobile has markedly affected the condition of the highways of Pennsylvania. There are now 90,000 miles of roads, of which 16,000 miles are improved. During 1925 there were issued 1,200,000 automobile licenses.

Many towns need sewer systems and sewage treatment works; many surface waters must be clean as they are the chief source of public water supplies. Industry and the development of natural resources are dominant factors. Reforestation will tend to improve streams. Fishing, outdoor recreation and the extensive use of the automobile take the citizens out into the open country.

The fishermen, hunters and other outdoor recreationists are demanding abatement of all stream pollution. Water-works operators are urging that pollution be controlled at least to such an extent that the raw water at the intake shall not place undue load upon normal purification processes. The citizens of most towns look with far more favor upon expenditure of public funds for improved pavements for their own use than for sewage-treatment works for the benefit of down-stream neighbors. Industry must consider the cost of treatment of industrial waste, since it is passed on to the consumer in an increased price of the manufactured products.

These statements show the magnitude and complexity of the problem of conservation and utilization of the water resources of Pennsylvania confronting the state authorities.

Existing Anti-Stream Pollution Statutes

For the protection of the public health, the discharge of sewage into the waters of the state is prohibited by law, except, *inter alia*, from municipally owned sewers where a permit may be issued stipulating the conditions under which such discharge may legally be made. Hence, there is discretionary power vested in the state authorities as to degree of treatment of municipal sewage. Plans of sewers and sewage treatment works must be approved prior to construction.

The discharge to the streams and lakes of substances detrimental to fish life is specifically prohibited by law, but there is now no statutory authority to legalize the discharge, even though it be treated, as in the case of sewage.

The mining of coal is one of the major industries of Pennsylvania. The water drained or pumped from coal mines is acid in reaction, due to the presence of sulphuric acid formed from the iron pyrites in the coal.

In the well-known Sanderson case (Penna. Coal Co. *v.* Sanderson, 113 Pa. 126) the Supreme Court of Pennsylvania upheld the right of the coal company to discharge such mine drainage to the waters of the state, and thereafter several anti-stream pollution statutes specifically excepted mine drainage from their provisions.

This decision rests upon two grounds: first, that in pumping water from its mines so as to cause it to enter a stream the defendant was making a natural use of the stream; and second, that the vast importance to the community and the state of the coal-mining industry required the plaintiff, an individual, to give up the less important domestic use of the stream without compensation.

Recently a different case arose and a different answer was given by the Pennsylvania Supreme Court, to wit, in the Indian Creek Case, where the discharge of mine drainage menaced a public water supply used primarily for steam-raising purposes in railroad locomotives, but also as a domestic supply in municipalities with a population of about 75,000.

In this case the Supreme Court (Penna. R.R. *v.* Sagamore Coal Co., 281 Pa. 233) ordered the defendant coal companies to cease discharging their mine drainage to Indian Creek above the dam of the water company because of the large public interests in the use of the water of the stream, both for railroad purposes and for domestic use.

SANITARY WATER BOARD

In 1923, the administration of all anti-stream pollution statutes was vested in a Board of five ex-officio members called the Sanitary Water Board. It is composed of the Secretary of Health as chairman, the Secretary of Forests and Waters, the Attorney General, the Commissioner of Fisheries and the chairman of the Public Service Commission.

This Board superseded the Department of Health and the Commissioner of Fisheries in their former jurisdiction respectively as to sewerage and the discharge of industrial wastes. The Department of Health is by law the enforcement agent of the Board, and makes the investigations and reports.

When the Board organized and considered the problems with which it was confronted, a decision was soon reached that a broad, comprehensive plan must be adopted to secure a practicable program, and also that far better results would be accomplished through the state co-operating with municipalities and industry than through antagonistic enforcement of statutes.

A plan for the conservation of water resources to be sound and practicable must be predicated upon the highest degree of utilization of these waters for the benefit of the public.

The comprehensive plans of the Sanitary Water Board include the following principles:

The conservation of water resources consists in: —

(*a*) Maintenance of cleanly streams in that wholesome state and abatement of harmful pollutions in order to restore overtaxed streams to a cleanly condition where practicable so to do.

(*b*) Allocation of use for various purposes so that the greatest benefits to the public are derived therefrom instead of minor interests monopolizing these resources to the detriment of major interests.

(*c*) Regulation of streams for the reduction of floods and for increase of the rate of flow during periods of drought, which makes possible an improvement of sanitary quality of the water through increased dilution, and likewise reduces expense of treating polluting matter.

The highest use of water resources is: —

(*a*) For source of supply for water-works serving the public for domestic and municipal purposes.

Thereafter the utilization of water resources — generally, but not always applicable in every specific case — consists of: —

(*b*) For purposes of sanitation by the conveyance of sewage and industrial wastes after suitable treatment, when and where needed.

(*c*) For water for manufacturing and industrial purposes, for development of power, for agriculture and for navigation.

Briefly discussing the above principles, it is obvious that every possible effort should be made to maintain the streams which are now clean. Not only is there a present need, but as municipal and industrial development occurs in the future, the demand for clean water as a source of public and industrial supplies will increase and must be provided for.

As the natural surface waters belong to the state, subject to the rights of riparian owners to reasonable use as the water flows, their development and utilization to the highest degree of efficiency can only be attained through allocation by proper state authority.

As an illustration of the wastefulness of unregulated streams and the benefits attainable by regulation, the example may be cited of a river in the western part of Pennsylvania having a catchment area of 600 square miles and the following rates of flow:

	Cu. ft. per sec.
Extreme drought	20
Ordinary drought	60
Ordinary low flow	90
Ordinary flow	270
Extreme flood	25,200

A dam and storage reservoir is to be built near the headwaters of this river which will reduce the flood flows to 17,000 second feet. The release of the stored water during times of low flows will maintain a flow of between 400 and 450 second feet.

A flood on this unregulated river during 1913 wrought damages aggregating nearly $2,100,000, which is a greater sum than the total estimated cost of the dam and the reservoir project.

On the other hand, to maintain cleanly conditions at times of drought flow in the unregulated stream, the sewage of the towns along this river would have to be not only freed of settleable solids, but also oxidized. The regulated river could receive and inoffensively assimilate the untreated sewage from a materially larger population.

The use of this river as the source of several water supplies further indicates the effect upon the public health through improvement in sanitary quality of the raw water attainable by regulating the flow.

Unless an order of precedent for use of water be established, injustice and inefficient utilization is bound to occur. But it must be borne in mind that while public water supplies are paramount, the local conditions must always be considered in final determination of the order of the lower uses.

From the acceptance of these principles, it naturally follows that river systems must be studied in their entirety and then policies established for their various parts which will fit together to make a definite future plan of development and use.

Several of these fundamentals are set forth in the following resolution of the Sanitary Water Board, providing for the classification of the waters of the state:

> *Whereas*, The degree of pollution of the waters of the State varies widely from the pristine purity of a small stream flowing through a virgin forest to the grossly polluted stream draining a valley given over to intense municipal and industrial development; and
>
> *Whereas*, Such differences in condition and the present and probable future use of the streams must be recognized in determining the required degree of treatment of sewage and industrial wastes; and
>
> *Whereas*, The natural powers of streams to inoffensively assimilate and dispose of polluting matters by dilution must be utilized so far as compatible with the general interests of the public in order to establish a practicable and economical program for stream control; therefore
>
> *Resolved*, That the waters of the State be classified as follows:
>
> *Relatively Clean and Pure Streams*
>
> *Class "A."*— Streams in their natural state probably subject to chance contamination by human beings but unpolluted or uncontaminated from any artificial source, hence generally fit for domestic water supply after chlorination, will support fish life and may be safely used for recreational purposes.
>
> *Streams in which Pollution shall be Controlled*
>
> *Class "B."*— Streams more or less polluted, where the extent of regulation, control, or elimination of pollution will be determined by a consideration of (*a*) the present and probable future use and conditions of the stream; (*b*) the practicability of remedial measures for abatement of pollution; and (*c*) the general interests of the public through the protection of the public health, the health of animals, fish and aquatic life, and the use of the stream for recreational purposes.
>
> *Class "C."*— Streams now so polluted that they cannot be used as sources of public water supplies will not support fish life and are not used for recreational purposes; and also from the standpoint of the public interests and practicability it is not now necessary, economical or advisable to attempt to restore them to a clean condition; and further
>
> *Resolved*, That all artificial pollution of Class "A" streams shall be prohibited, and any sewage or industrial wastes on the watershed shall be treated to such a degree that the effluent shall be practically free from suspended matter, non-putrescent and

disinfected, and that recreational use shall not be sanctioned within prejudicial influence of water works' intakes; and further

Resolved, That the degree of treatment of sewage and industrial wastes discharged into Class "B" streams shall be determined for each particular stream or portion thereof after consideration of the general interests of the public and the economics of the particular case; and further

Resolved, That sewage and industrial wastes may be discharged into Class "C" streams; provided, however, that such discharge shall not create any public nuisance or menace to health.

To carry out these principles successfully it is essential that there be real co-operation between the state, the municipalities, the industries and the public.

The Board has had marked success in attaining such co-operation.

For example, the simultaneous construction of a system of intercepting sewers, pumping stations and sewage-treatment works by a municipality is often a heavy financial burden and sometimes is impossible. Arbitrary orders to do so are often of little avail. Therefore the engineers of the Board sit in conference with the engineers of the municipality and other appropriate officials and determine upon a program for the progressive construction of the sewerage project. Such program is then adopted by the council and submitted to the Sanitary Water Board for approval. This co-operation has resulted in many Pennsylvania municipalities inaugurating extensive sewerage projects which undoubtedly they would not have undertaken had an order been issued for the "forthwith" construction of the works.

Co-operation with industry is predicated upon other principles.

Certain industrial wastes contain by-products of value. Research has disclosed some and further research will find others. For the treatment of many industrial wastes much money has been expended by separate companies, sometimes with success and sometimes resulting in failure.

Usually it is impracticable to expect any one company to expend its own funds for extensive research and the design of structures which if found successful become applicable to their competitors at little cost.

The logical and economical way of solving such problems is through co-operation of the state and the various groups of industries, thus pooling their knowledge and reaching conclusions available to all who have participated therein at the minimum cost.

This is the plan of procedure of the Sanitary Water Board in dealing with the vexatious problem of industrial waste disposal.

Typical Results Attained in Past Two Years

A survey is under way of the smaller streams. Fish wardens and forest rangers make actual traverse to find those streams which are now unpolluted from any artificial source. Based upon their reports the Sanitary Water Board has already designated 4,575 miles of streams as Class "A." Abatement of first sources of pollution, so far attained, has extended the length of these clean streams by 70 miles.

Five years ago there were only four sewage treatment works on the watershed of the Beaver River. As a result of applying a uniform, consistent and equitable policy to all the municipalities involved, there are now nine such works completed and in operation, three under construction, three municipalities have provided the funds to begin construction, and four others have submitted plans which have been approved and funds for their construction will soon be available.

An example of co-operation between a single industrial plant and the Board is the case of a very large glue works against which bitter protest was made because of discharge of wastes alleged to interfere with the recreational use of a stream. About 7,000 petitioners engaged an able attorney to press for immediate abatement. The condition of the river was bad. Litigation would have been tedious and destructive. The company engaged expert engineers to study the problem in a constructive fashion. The Board, recognizing the good faith shown, have afforded the company's engineers adequate time for study and the progressive construction of treatment works. Presently an abatement will be obtained, the complainants satisfied and all accomplished without any resort to the courts.

The first attempt of the Board to co-operate with a group of industrial concerns was with the leather tanners. A conference was called of technical representatives of that industry and the engineers of the Board. This group recommended a joint investigation and operation of a full-scale tannery waste treatment works.

Next came a meeting of the executives of the industry with the Sanitary Water Board, when a definite plan of procedure was submitted and approved. This resulted in the execution of an agreement by the tanning companies in Pennsylvania, whereby they are providing a fund of $35,000. Under the agreement, a committee, consisting of three chief engineers and three chief chemists of the tanning companies and the chief engineer of the Sanitary Water Board, are conducting research in a laboratory, the construction and operation of an experimental treatment works, and scientific study of the stream receiving the waste.

One of the interesting matters which is being studied is the rate at which a relatively cleanly stream above the tannery can inoffensively assimilate tannery waste: (1) untreated, when and as produced; (2) untreated, but certain acid and alkaline wastes premixed and then slowly discharged to the stream; (3) treated to varying degrees.

The mere retention of industrial wastes and their discharge over a twenty-four-hour period instead of during the usual eight hours is equivalent, so far as the maximum load upon the stream is concerned, to artificial treatment to reduce the polluting characteristics by two-thirds.

The second co-operative arrangement is with the pulp and paper industry. Again a technical committee representing that industry has been created and is at work studying the problems.

This industry has a national organization of executives and another of its technical men. In the latter is a "committee on waste" which has been at work for three or four years endeavoring to find ways and means of eliminating waste in pulp and paper manufacture. This has resulted in marked reduction in stream pollution from those mills which have installed such devices. However, there are unsolved problems such as the disposal of "sulphite" waste, and a movement has now been inaugurated by the Pennsylvania Committee to have such investigations made by the Forest Products Laboratory, United States Department of Agriculture, to be financed by the entire industry and the data made available to all confronted with the problem of disposal of pulp and paper mill wastes.

The Sanitary Water Board also has carried the spirit of co-operation outside the State of Pennsylvania by entering into interstate stream conservation agreements with New Jersey, Ohio, West Virginia and New York.

In the last analysis these agreements really mean that the state officers have agreed to exercise conscience and ignore the state line, if a pollution in one state harms the citizens of the adjoining state.

Delaware River Compact

The governors of Pennsylvania, New York and New Jersey, pursuant to authority of acts of the respective legislatures in 1923, appointed commissioners to negotiate a compact "for the regularization of the flow of the Delaware River, the conservation of the water resources of the Delaware Basin, the apportionment thereof among the said states for domestic and municipal supply, and the utilization thereof for power and other beneficial uses."

The commissioners of each state appointed engineering and legal experts to study the problems and advise them concerning technical and legal matters. These advisers held forty-two formal meetings, most of which lasted for two or three days, and many informal meetings for preparation of data. The joint commission held seventeen formal meetings and the commissioners of each state frequently met separately.

The resulting compact was formally executed by the commissioners on January 24, 1925.

This compact defines the rights of the three states as riparian owners in the water of the Delaware River. It gives to each state the right to develop tributaries within its own borders in accordance with its own regulations governing such matters, but restricts such development for diversion to 60 per cent of the drainage area of the Delaware River within the state. The share of each state in the water of the Delaware River is reduced in proportion, as it may make developments for diversion on its tributaries.

It provides an order of importance and public value for the development, use or diversion of the waters of the Delaware River, placing public water supplies first.

It prohibits the drying up of the river below any dam, and requires that at all times a quantity greater than the minimum flow must be left in the stream. These provisions for release of water from storage reservoirs will materially increase the summer low flows below the dams, and thereby not only increase the amount of available water at such times, but also proportionally improve its sanitary quality.

It constitutes the channel of the Delaware River as a carrier for water developed on a tributary or by a dam across the channel, in order that water so developed may be carried to any point lower down where it may be taken out of the channel.

It provides for the construction of dams across the river for storage or for power development, and for intakes to make possible the removal of water from the river.

It provides that all sewage discharged to the channel of the Delaware River above the confluence of the Lehigh River shall be treated to remove settleable solids, to render the effluent non-putrescible, and to effect a reasonable reduction of B. coli, and below the Lehigh it requires removal of settleable solids and discharge through submerged outlets, provided a higher degree may be required in specific instances to protect the public health.

It requires that the sanitary condition of the waters of the tributary streams at their confluence shall be at least equal to the sanitary condition of the Delaware River immediately above the confluence.

A temporary exception to this is made in the case of the Lehigh River because of lack of present major use of the Delaware River for many miles below the Lehigh.

It requires that industrial wastes discharged to the Delaware River or its tributaries shall be treated to such extent, if any, necessary to maintain in the channel of the Delaware River sanitary conditions equivalent to those which would be attained by the required degree of treatment of sewage, provided that taste and odor producing substances shall not be permitted to affect public water supplies derived from the Delaware River.

Joint projects between two or more states are authorized, and provision is made for the settlement of controversies between states, and a permanent commission to approve of projects and observe their operation is provided for.

It will be possible under this compact to develop the latent resources of the Delaware River to their fullest extent for water supply, hydro-electric power or any other purpose. Up to the present time the water, which these resources represent, has flowed to waste because of the uncertainty as to what any state might do in the way of conserving and utilizing them.

This compact defines the right of the states and confers great benefits upon all of them.

CONCLUSION

Two years' experience of the Sanitary Water Board of Pennsylvania in the administration of statutes relevant to sewerage and stream pollution in accordance with a comprehensive plan, as briefly outlined above, has demonstrated that sane conservation and utilization of water resources can be attained through co-operation between the state, its municipalities, its industries and its citizens.

STRESSES IN A COMPOSITE MEMBER SUBJECTED TO BENDING AND DIRECT STRESS

By B. A. Rich and W. W. Bigelow,* Members, Boston Society of Civil Engineers

(Presented before the Designers Section, Boston Society of Civil Engineers, on January 13, 1926)

This article describes a method which has been devised, and used, by the authors for determining the unit stresses in structural members acted upon by forces which tend to produce both bending and direct stress. Each member may be composed of one, or more than one, material. The materials may be capable of resisting either tension or compression, or both.

The method is particularly applicable to the design of reinforced concrete, where the reinforcing is capable of resisting either tension or compression and the concrete is assumed capable of resisting only compression. It is also applicable to the design of homogeneous, as well as non-homogeneous members; and of members where the cross-section is so irregular as to make algebraic methods impracticable, if not impossible.

The following work is divided into five parts: Outline of Method, Method in Detail, Theory of Method, Typical Applications of Method, and Appendix.

Outline of Method

The most indeterminate thing in the design of a member composed of more than one material and subjected to both bending and direct stress seems to be the location of the neutral axis of the member. The special feature of this work consists in the graphical method employed in locating this axis. To complete the work a method of determining actual stresses is also developed.

The method of locating the neutral axis may be outlined as follows:

The cross-section of the member is drawn in a similar manner to that shown for a reinforced concrete member in the upper portion of Fig. 1. A force diagram, for forces representing subdivisions of the section, is drawn at the lower left, and a funicular polygon for these

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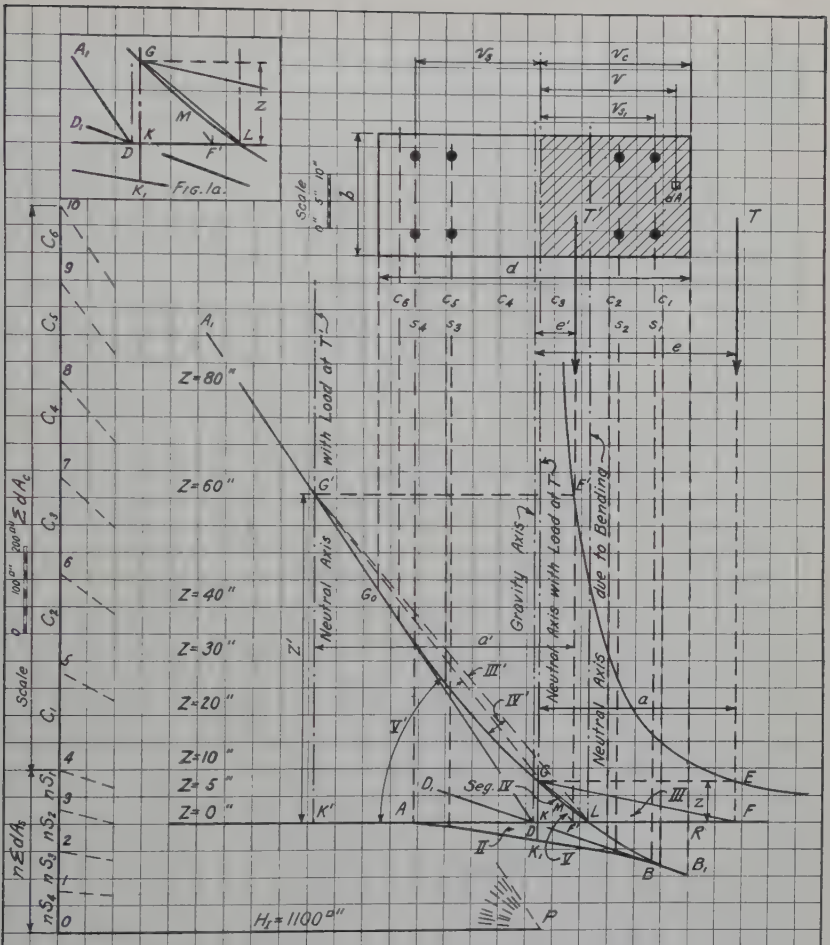

Calculations for II

6.8 × ½ × 0.7	= 2.4
25.5 × ½ (0.7+5.0)	= 72.8
5.2 × ½ (5.0+2.5)	= 19.5
6.6 × ½ (2.5+0.6)	= 10.2
6.9 × ½ × 0.6	= 2.1
51.0 = AR	107.0
Area AB₁LA = II = ↗	

	Seg. IV	III = II − IV	Equation for Curve E-E' $LF = 2\frac{III}{z}$
Z	Area LGML	Area AB₁LA − Area LGML	$LF = 2\frac{(\text{Area } AB_1LA - \text{Area } LGML)}{z}$
5.0	8.5 × 0.2 × ⅔ = 1.1	105.9	42.4
10.0	15.9 × 0.4 × ⅔ 4.2	102.8	20.6
20.0	29.4 × 1.0 × ⅔ = 19.6	87.4	8.7
30.0	42.3 × 1.6 × ⅔ = 45.1	61.9	4.1
40.0	54.3 × 2.4 × ⅔ = 86.8	20.2	1.0
60.0	78.5 × 3.7 × ⅔ = 193.5	− 86.5	−2.9
80.0	102.2 × 4.2 × ⅔ = 286.0	−179.0	−4.5

FIG. 1.—GRAPHICAL METHOD OF LOCATING NEUTRAL AXIS

forces is drawn below the cross-section. A curve called, for want of a better name, the E–E' curve is determined and plotted at the right of the funicular polygon. The reason for these steps is explained later.

If T represents any compressive force (applied in the plane of one of the principal axes of and normal to the cross-section) the corresponding neutral axis is found by producing the line of action of the force until it cuts the E–E' curve. Through this point a horizontal line is drawn intersecting the funicular polygon. A vertical line passing through this latter point of intersection, G, lies on the neutral axis of the section due to the force T. The same E–E' curve and the same funicular polygon can be used for any position of T at the right (as the figure is drawn) of the gravity axis. For example, the neutral axis due to a force T' is determined in a similar manner and found to be on the vertical line passing through G'.

Having located the neutral axis, stresses at any point in the member may be calculated by substituting values from the graphical work in a simple formula.

METHOD IN DETAIL

A symmetrically reinforced concrete member is selected for illustration, and a cross-section of it is shown in Fig. 1. It is rectangular in outline, having a breadth b and a depth d. It is acted upon by an eccentric, compressive force, T, located at a distance e to the right of the gravity axis of the section. For convenience the cross-section shown in the figure has been rotated through an angle of 90 degrees, and appears in the same plane as the force.

The customary assumptions for concrete, as recommended by the "Joint Committee on Standard Specifications for Concrete and Reinforced Concrete," * are adopted.

Co-ordinate paper is used to facilitate plotting. The right-hand edge of the cross-section is located on one of the vertical lines of the paper. Beginning at the right, the concrete is divided into a number of small equal areas, with, as is usually the case, a smaller area remaining at the left. The width of each of the equal areas is taken as two divisions of the co-ordinate paper. Lines passing through the centers of gravity of the equal areas thus coincide with vertical lines of the paper. These lines, marked c_1, c_2, — c_5, are treated as the lines of action of the forces C_1, C_2, — C_5, representing the equal concrete areas. The line marked c_6 indicates the line of action of the force C_6, representing the remaining concrete area at the left of the cross-section. Lines drawn through the

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* Proceedings, American Society of Civil Engineers, October, 1924.

centers of gravity of the different groups of rods are marked s_1, s_2, s_3 and s_4, and are treated as the lines of action of the forces nS_1, nS_2, nS_3 and nS_4. Where n equals the ratio of the modulus of elasticity of steel to that of concrete, the values nS_1, nS_2 represent the area of the steel transformed to an equivalent area of concrete.

The force diagram, *P–O-10*, is laid off at the left of the figure. The forces are plotted in upward order, beginning with the steel "forces" (the one at the left first and proceeding to the right), then the concrete "forces" (the one at the right first and proceeding to the left). The magnitude of the C forces is taken as the gross area of each of the subdivisions of the concrete. The magnitude of the nS forces is taken as n times the area of the steel. The area occupied by the steel is thus counted twice, once as steel and once as concrete. An error is thus introduced at this point in the compression area, but it is too small for further consideration. The pole P is selected at a point which is H_I distant, in a horizontal direction, from the lower end of the diagram. The value of H_I is so selected that the upper ray *P–10* makes an angle of about 60 degrees with the horizontal, and such that its value can be readily used in multiplying.

A funicular polygon A–B–B_1 is drawn for the forces nS_1, nS_2, nS_3 and nS_4, representing the steel areas. The first string of the polygon is laid out from the point A, which lies on the line of force representing the transformed area of the group of rods at the left of the cross-section. This string (produced to F, the point of its intersection with the line of thrust T) is a horizontal line, as the ray P–O of the force diagram has been made horizontal. The object of arranging the force diagram to have this string horizontal will be seen later. The string B–B_1 is drawn through the point B, which lies on the line of force representing the transformed area of the group of rods at the right of the section. The point B_1 lies on the vertical line passing through the right-hand boundary of the concrete area. The string B–B_1 is parallel to the ray *P–4* of the force diagram, and is produced to an indefinite point D_1, cutting the line A–F at the point D. The portion of the figure adjacent to D is shown at a larger scale in the insert Fig. 1*a*.

A funicular polygon B_1–L–A_1 is drawn for the concrete. This polygon approaches a curve as the number of small divisions, into which the concrete is divided, approaches infinity. This curve is shown in Fig. 1. To construct it a funicular polygon is drawn for the forces C_1, C_2, — C_6, representing the concrete areas. As this would so closely coincide with the curve B_1–A_1 it is not shown. The first string of this polygon is laid off from B_1, parallel to the ray *P–4* of the force diagram.

This string thus coincides with the string $B–B_1$ of the funicular polygon for the steel. The last string is laid off parallel to the ray $P–10$, beginning at the point G_0 and extending to the indefinite point A_1. The point G_0 on the funicular polygon is at the intersection of the vertical line passing through the left-hand boundary of the concrete area. The string $A_1–G_0$ produced intersects the line $A–F$. It will be shown in the "Theory of Method" section of this paper that this intersection is at the point D, as already determined. The curve $B_1–A_1$ for the indefinite number of divisions is drawn tangent to the strings of the polygon for the definite number of small areas into which the concrete is divided. The curve is a parabola from B_1 to G_0.

The $E–E'$ curve is determined from equation (19), developed in the section on "Theory of Method."

$$(19) \qquad LF = \frac{2\,III}{Z}$$

where L is the point of intersection of the string of the funicular polygon parallel to the ray $P–O$ of the force diagram, and the funicular polygon for the concrete, and LF is the distance, on the above string produced, from L to the line of action of T.

The Roman numerals are used to denote the following areas:

$II = ALB_1A$
$III =$ Triangle $FLGF$
$IV =$ Segment $LMGL$ (M being any point between G and L on the polygon $A_1–L–B_1$)
$V = LKGML$

It is shown later by equation (16) that the area III must be made equal to area II minus area IV.

The area II is scaled and computed in the lower part of Fig. 1. Several values of Z (the vertical distance KG, from the string $A–F$ to the funicular polygon for the concrete) are assumed. For each value of Z a horizontal line is drawn at a distance Z above this string, and where this line intersects the funicular polygon for the concrete is called point G, which is on the vertical line through the neutral axis due to a force T located a distance LF, to be determined, from L. (These values of Z are assumed so that co-ordinate lines of the paper are used for the horizontal lines.) For each value of Z there is a corresponding location of G, and corresponding values for the areas IV and III. The area IV is computed for each value of Z, and the results are shown in the second column of the tabular form at the bottom of Fig. 1. Area *III* is then determined by subtracting the various values of area *IV* from area *II* and these are tabulated in the third column. Values of *LF* are then worked out from equation (19) and are tabulated in the last column. The E–E' curve is then plotted, using the values of *LF* as abscissa, from *L* as the origin, "plus" values to the right and "minus" to the left, and using the values of Z as ordinates.

The neutral axis for any location of T can easily be found from the E–E' curve. The line of action of the force T located at a distance e from the gravity axis cuts the E–E' curve at a point E. A horizontal line is drawn through E, intersecting the funicular polygon for the concrete at a point G. This particular point G lies on a vertical line which locates the neutral axis due to this particular location of T.

Stresses in the member may now be determined by substituting values in equation (23), the development of which is shown further on in this article.

$$(23) \qquad f=\frac{Tv}{H_I Z}$$

where the value and location of T are known. v is the distance from the point where the unit stress is desired to the neutral axis, due to the location of T. H_I is the pole distance employed when the force diagram was drawn. Z is the vertical distance GK determined by the location of T.

The member chosen in Fig. 1 to illustrate the general proposition might be considered as representing the cross-section of an arch ring of a reinforced concrete bridge. After the E–E' curve is drawn for any definite cross-section, very little work is required to determine stresses in the member due to different magnitudes and positions of the thrust. The method thus lends itself readily to the investigation of stress conditions in an arch subjected to the different conditions of load, usually employed in bridge design.

Theory of Method

The data assumed and the example used are the same as in the preceding section. Reference is made to Fig. 1.

If we replace the areas of the reinforcement, in the planes of reinforcement, by concrete n fold we transform the composite member into a homogeneous member having equivalent elastic characteristics. We can now let —

dA = Any elementary portion of the transformed section.
f = Unit stress on dA.
v = Distance dA to the neutral axis of the member.
I_r = Moment of inertia of the concrete area in compression and the transformed steel areas in compression and in tension, referred to the neutral axis for the given T.
M_r = Statical moment of the concrete area in compression and the transformed steel areas in compression and in tension, referred to the neutral axis for the given T.

And since the member is in equilibrium, the external force is equal to the algebraic sum of the internal forces, we can write the following equations:

$$(1) \qquad T = \Sigma dAf$$

but $\frac{f}{v}$ is a constant, therefore —

$$(2) \qquad T = \frac{f}{v} \Sigma dAv$$

If we let a be the distance from the line of action of thrust T to the neutral axis resulting from T, the statical moment of the forces about the neutral axis is as follows:

$$(3) \qquad Ta = \Sigma dAfv = \frac{f}{v} \Sigma dAv^2$$

multiplying equation (2) by a the following is obtained:

$$(4) \qquad Ta = \frac{af}{v} \Sigma dAv$$

combining equations (3) and (4) we have

$$(5) \qquad \frac{f}{v} \Sigma dAv^2 = \frac{af}{v} \Sigma dAv; \text{ or —}$$

$$(6) \qquad \Sigma dAv^2 = a \Sigma dAv$$

by definition

$$(7) \qquad I_r = \Sigma dAv^2; \text{ and —}$$

$$(8) \qquad M_r = \Sigma dAv$$

therefore, from equations (6), (7) and (8) we have —

$$(9) \qquad I_r = aM_r; \text{ or —}$$

$$(10) \qquad a = \frac{I_r}{M_r}$$

The force diagram and funicular polygons are drawn as previously described and are shown in Fig. 1.

It can be shown that any vertical intercept between the funicular polygon A–B–B_1 for the steel, and the horizontal string A–F, multiplied by the pole distance H_I, is equal to the statical moment of n times the steel areas to the left of, and about, the vertical line on which the intercept is measured.* Any vertical intercept between the funicular polygon A–B_1 and the string B_1–D_1 multiplied by the pole distance H_I is equal to the statical moment of n times the steel areas to the right of, and about, the line of interception. As the point D is common to the line A–F and the line B_1–D_1, the vertical intercept from D to the string A–B_1 multiplied by the pole distance H_I, is equal to either the statical moment of n times the steel areas to the right of, or to the left of, the vertical line passing through D. The point D therefore lies on the gravity axis of the steel areas in the section.

Any vertical intercept between the funicular polygon B_1–L–A_1 for the concrete and the string B_1–D_1, multiplied by H_I, is equal to the statical moment of the concrete areas to the right of, and about, the line of interception. Any vertical intercept between the funicular polygon B_1–L–A_1 and the string A_1–D, multiplied by H_I, is equal to the statical moment of the concrete areas to the left of, and about, the line of interception. The vertical intercept drawn through the point of intersection of the string B_1–D_1 and the string A_1–D, multiplied by H_I, is equal to either the statical moment of the concrete area to the right of, or to the left of, the vertical line passing through this point. This point then lies on the gravity axis of the concrete area in this section.

The point D has been found to lie on the gravity axis of the steel areas and on the string B_1–D_1. The point of intersection of the strings B_1–D_1 and A_1–D is seen to lie on the gravity axis of the concrete area. But as the cross-section is symmetrical the gravity axis of the steel areas coincides with the gravity axis of the concrete area. Therefore the point D is the point of intersection of the strings B_1–D_1 and A_1–D as well as the point of intersection of the strings A–F and B_1–D_1.

Any vertical intercept between the funicular polygon B_1–L–A_1 for the concrete and the funicular polygon B_1–A for the steel, multiplied by H_I, is equal to the statical moment of n times the steel areas and the concrete areas to the right of, and about, the line of interception. At L, the point of intersection of the polygon B_1–L–A_1 and the line A–F, the intercept multiplied by H_I is equal to the statical moment of the concrete area, plus the statical moment of n times the steel areas to the right of, and about, the line of interception. At this point the intercept multiplied by H_I is also equal to the statical moment of n times the steel areas to the left of, and about, the line of interception. The point L therefore lies on the neutral axis when the member is subjected to bending alone.

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* See Appendix.

Consider a point G to the left of the point L on the funicular polygon B_1–L–A_1. Let K be the point of intersection of a vertical line through G and the horizontal line A–F. Let K_1 be the point of intersection of this vertical line and the funicular polygon A–B–B_1. The vertical intercept G–K_1, multiplied by H_I, is equal to the statical moment of the concrete area, plus n times the steel areas to the right of, and about, this vertical line through G. The intercept K–K_1, multiplied by H_I, is equal to the statical moment of n times the steel areas to the left of, and about, this line through G. The difference between the statical moments of these areas to the right of, and to the left of, this vertical line through G is equal to $(GK_1 - KK_1 = GK)$ times H_I. This value of GK times H_I is equal to the statical moment of the concrete area in compression, plus the statical moment of n times the steel area in compression, minus the statical moment of n times the steel area in tension, referred to the axis through G. This quantity is equal to the statical moment of the total cross-section of the member, which has previously been designated as M_r.

If we let Z equal any vertical intercept between the lines L–A_1 and L–A, we have $GK = Z$, and —

$$(11) \qquad M_r = ZH_I$$

The moment of inertia of the concrete area, and n times the steel areas to the right of, and about, the axis passing through G, is equal to $2H_I$ times the area GB_1BK_1G.* The moment of inertia of the steel areas to the left of, and about, the same axis is equal to $2\ H_I$ times the area AKK_1A. The sum of the moments of inertia of the areas to the right and to the left of the axis is equal to $2\ H_I$ (area GB_1BK_1G + area AKK_1A) $= 2\ H_I$ (area $AKGB_1K_1A$).

Let I_r equal the moment of inertia of the area of concrete in compression, plus the moment of inertia of n times the steel in compression, plus the moment of inertia of n times the area of steel in tension.

Roman numerals are used to denote the following areas:

$II = ALB_1A$
$III =$ Triangle $FLGF$

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* See Appendix.

IV = Segment $LMGL$ (M being any point on the funicular polygon A_1–L–B_1, between G and L)

$V = LKGML$

Making use of the above notation, we have —

(12) $$I_r = 2\,H_I\,(II + V)$$

The point G has been considered as any point to the left of the point L on the funicular polygon B_1–L–A_1. If we now consider the special position of the point G which locates it at the intersection of the polygon and the vertical line through the neutral axis of the cross-section, resulting from the action of the thrust T, as shown in Fig. 1, the values of M_r and I_r from equations (11) and (12) can be substituted in equation (10), as follows:

(13) $$a = \frac{I_r}{M_r} = \frac{2\,H_I\,(II+V)}{H_I Z} = \frac{2\,(II+V)}{Z};\ \text{or}$$

(14) $$\frac{aZ}{2} = II + V$$

but from Fig. 1 —

(15) $$\frac{aZ}{2} = \text{Area of triangle } KGFK = III + IV + V$$

therefore —

(16) $$II = III + IV$$

To find the special position of the point G which locates the neutral axis as just described, it is only necessary to bring about the conditions of equation (16). The value of II is dependent only on the section used and can be determined from the figure by scaling. It is found convenient to treat the area represented by II as being the sum of a number of small divisions, the sum of whose horizontal dimensions is equal to A–R, the horizontal dimension of the total area. It is seen from the figure that, as the value of LF is constant for a given position of T, the values of III and IV vary with different values of Z. The problem now is to determine the value of Z, such that the conditions of equation (16) shall obtain.

From the figure it is seen —

(17) $$III = \left(\frac{LF}{2}\right) Z;\ \text{and}$$

(18) IV = Chord LG multiplied by ⅔ the middle ordinate.

From equation (17) —

$$LF = 2\left(\frac{III}{Z}\right) \tag{19}$$

or substituting equation (16) —

$$LF = \frac{2\,(II-IV)}{Z} \tag{20}$$

When e is larger than d the value of IV is negligible and we have —

$$Z = 2\left(\frac{II}{LF}\right) \tag{21}$$

which locates the desired position of G and the neutral axis.

When e is less than d the desired value of Z can be conveniently determined by using the curve E–E', in Fig. 1. This curve is a plot of equation (19). The computations for this curve are shown in tabular form in Fig. 1. The assumed values for Z and the corresponding computed values for LF are laid off from co-ordinate axes passing through L, Z vertical and LF horizontal, and the curve E–E' drawn. The line AF becomes one of the axes and the reason for arranging to have this line horizontal is now evident. The line of action of the thrust T cuts this curve at E. The ordinate EF gives the desired value of Z. A line through E parallel to AF cuts the funicular polygon B_1–L–A_1 at the point G, which is located on the vertical line through the neutral axis of the cross-section, resulting from the action of the thrust T.

The stresses in the member caused by the thrust T are found by combining equations (3), (7), (12) and (14).

$$Ta = \frac{f}{v}\Sigma dAv^2 = \frac{f}{v}I_r = \frac{f}{v}2\,H_I\,(II+V) = \frac{f}{v}H_IaZ \tag{22}$$

$$f = \frac{Tav}{H_IaZ} = \frac{Tv}{H_IZ} \tag{23}$$

As f was taken as the average unit stress on any elementary portion of the transformed section, it represents unit stresses in the concrete. If the transformed steel areas are now replaced by the original steel areas, the unit stress in the steel will be n times the unit stress in the corresponding transformed area.

The line of action of the thrust T, as shown in Fig. 1, for the preceding work, is not only located to the right of the gravity axis of the section but is at the right of the point L. Had it been located to the right of the gravity axis, and come at the left of the point L, conditions would have been slightly different, but the same line of reasoning would have held. This case will now be considered briefly.

The same symbols are again employed and in the same manner, except where they now represent new values they are "primed." The thrust T' is shown in Fig. 1, located at a distance e' to the right of the gravity axis of the section. The value of e' is less than DL and T' is at the left of L. Long dash lines are used in connection with this position of T'.

Corresponding to equation (14), we now have —

$$(24) \qquad \frac{a'Z'}{2} = II + V'$$

The Roman numerals denote the following areas:

$III' = \text{Triangle } F'G'LF'$
$IV' = \text{Segment } LG_OG'L$
$V' = LK'G'G_OL$

From Fig. 1 —

$$(25) \qquad \frac{a'Z'}{2} = \text{Area of the triangle } K'G'F'K' = IV' + V' - III'$$

therefore —

$$(26) \qquad II = IV' - III'$$

from the figure it is seen —

$$(27) \qquad III' = \left(\frac{LF'}{2}\right) Z'; \text{ or}$$

$$(28) \qquad Z' = 2\left(\frac{III'}{LF'}\right)$$

substituting the value of III' from equation (26) —

$$(29) \qquad Z' = -\frac{2(II - IV')}{LF'}$$

which is comparable to equation (20), the negative sign indicating that LF' is measured to the left of the point L.

Stresses in the member caused by the thrust T' are found from —

$$(30) \qquad f = \frac{T'v}{H_I Z'}$$

which is comparable to equation (23).

In other words, the stresses in the member can be determined for any position of the thrust to the right of, or to the left of, the point L, from e equal to zero to e equal to infinity. When e equals zero the member is subjected only to direct stress. When e equals infinity the member is subjected only to bending. Between these two limits stresses in the member can be found from the general equation —

$$(23) \qquad f=\frac{Tv}{H_I Z}$$

TYPICAL APPLICATIONS OF METHOD

Hollow Reinforced Concrete Column

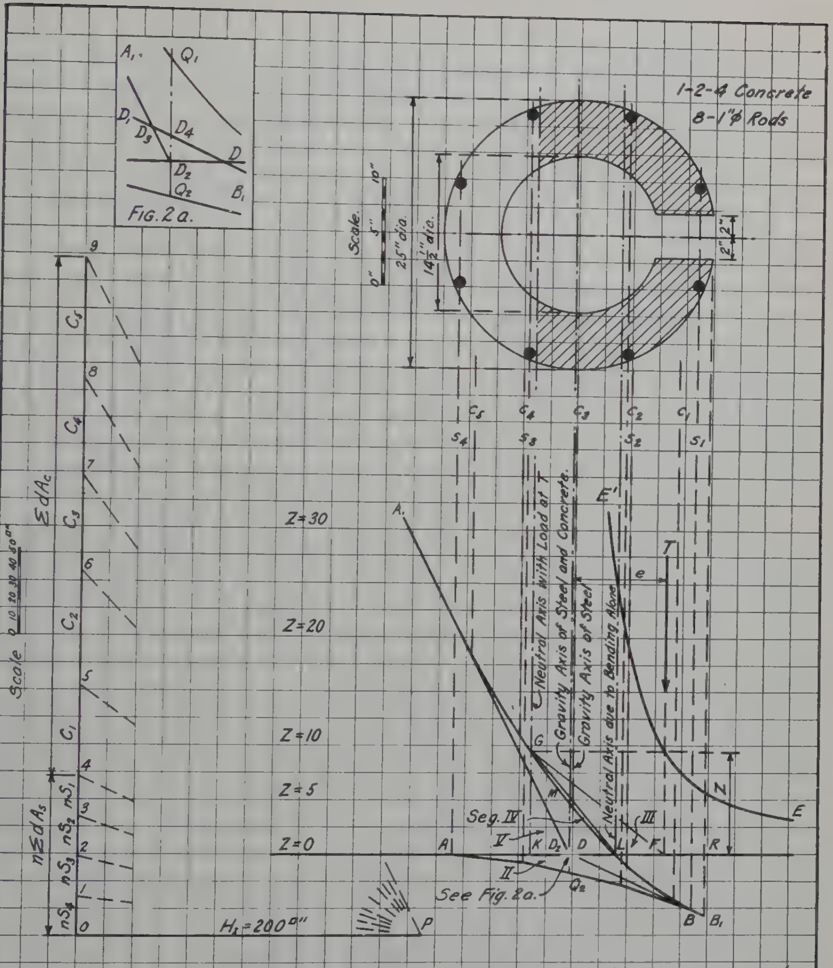
The cross-section of a hollow reinforced concrete column is shown in Fig. 2. The space in the center was provided for ventilating the building in which this type of column was used. The section taken is through the weakest part of the column, which is located at the outlet from the ventilating duct to the room. The column was assumed to be loaded in such a manner as to produce maximum compressive stresses.

The column as built has an outside diameter of 28 inches, but as the shell of 1½ inches is considered as fireproofing and of no value in strengthening the column, the cross-section is shown 25 inches in diameter. The reinforcement consists of eight bars one inch in diameter, equally spaced on a 24-inch diameter circle which locates their centers. The concrete specified is 1 : 2 : 4. The value of n is taken as 15.

The column was designed to resist a bending moment of 47,000 foot pounds, and an axial load of 66,000 pounds, acting simultaneously.

The funicular polygon A–B_1–L–A_1 is constructed in a similar manner to the corresponding polygon in Fig. 1. The strings produced from A_1 and B_1 do not, however, intersect at a common point located on the horizontal string through A, as they do in the previous case, this cross-section being unsymmetrical about its vertical axis. The string through B_1, parallel to the ray P–4 of the force diagram, intersects the horizontal string AF at D, while the string through A_1, parallel to the ray P–9, intersects AF at D_2. These strings from B_1 and A_1 intersect each other at D_3. The portion of the figure at the point D is enlarged and shown diagrammatically in the insert (Fig. 2a).

The vertical line passing through D_2 (Fig. 2a) intersects the funicular polygon B_1–L–A_1 at point Q_1. It intersects the string B_1–D (produced) at the point D_4, and intersects the funicular polygon A–B–B_1 at the point Q_2.



Calculations for II		
6.6 × ½ × 0.7	=	2.3
8.5 × ½ (0.7 + 2.7)	=	14.5
0.6 × ½ (2.7 + 2.2)	=	1.5
4.6 × ½ (2.2 + 0.3)	=	5.7
3.0 × ½ × 0.3	=	0.4
23.3 = AR		24.4

Area AB,LA = II =

	Seg. IV	III = II + IV	Equation for Curve E-E' $LF = 2\frac{III}{Z}$
Z	Area LGML	Area AB,LA − Area LGML	$LF = 2\frac{(\text{Area AB,LA} - \text{Area LGML})}{Z}$
5	6.7 × 0.1 × ⅔ = 0.4	24.0	9.6
10	13.0 × 0.4 × ⅔ = 3.5	20.9	4.2
15	18.8 × 0.6 × ⅔ = 7.5	16.9	2.3
20	24.5 × 0.9 × ⅔ = 14.7	9.7	1.0
25	30.3 × 1.3 × ⅔ = 26.2	−1.8	−0.1
30	35.5 × 1.5 × ⅔ = 35.5	−11.1	−0.7

FIG. 2.—REINFORCED CONCRETE COLUMN

The vertical intercept from D to the string A–B–B_1, multiplied by the pole distance H_I, is equal to either the statical moment of n times the steel areas to the right of, or to the left of, and about this vertical line through D. The statical moment of the steel areas to the left being equal to the statical moment of the steel areas to the right, the point D lies on the gravity axis of the steel areas in the section.

Any vertical intercept between the funicular polygon B_1–L–A_1 and the string B_1–D_1, multiplied by H_I, is equal to the statical moment of the concrete area to the right of, and about, the line of interception. Any vertical intercept between the same polygon and the string A_1–D_2, multiplied by H_I, is equal to the statical moment of the concrete area to the left of, and about, the line of interception. The vertical intercept between this polygon and the point D_3, multiplied by H_I, is equal to the statical moment of the concrete area to the right of, or to the left of, and about this line through D_3. This point D_3 therefore lies on the gravity axis of the concrete area of the cross-section of the member.

The sum of the intercepts Q_1–D_2 and D_2–Q_2, multiplied by H_I, is equal to the statical moment of the concrete area plus n times the steel areas to the left of, and about, the line of interception. The sum of the intercepts Q_1–D_4 and D_4–Q_2, multiplied by H_I, is equal to the statical moment of the concrete area plus n times the steel areas to the right of, and about, the line of interception. But as $Q_1D_2+D_2Q_2=Q_1D_4+D_4Q_2 =Q_1Q_2$, which determines the statical moment of the sum of the concrete area and n times the steel areas to either the left of, or the right of, and about the line passing through the point D_2, the point D_2 therefore lies on the gravity axis of the cross-section.

The E–E' curve is determined in a manner similar to that previously described. Then by obtaining the value of e the thrust T can be located and the value of Z determined as before.

The value of e is found by dividing the external moment by the thrust.

$$e=\frac{47{,}000 \text{ ft. lbs.}\times 12}{66{,}000 \text{ lbs.}}=8.55 \text{ in.}$$

The compressive stress in the concrete in the extreme fiber located at the right-hand side of the cross-section is found from equation (23).

$$f=\frac{Tv}{H_IZ}=\frac{-66{,}000 \text{ lbs.}\times 16.3 \text{ in.}}{200 \text{ sq. in.}\times 9.5 \text{ in.}}=-567 \text{ lbs. per sq. in.}$$

Tension in the reinforcing at the extreme left of the cross-section is equal to —

$$n\frac{Tv}{H_IZ}=15\frac{-66{,}000\text{ lbs.}\times(-7.2\text{ in.})}{200\text{ sq. in.}\times 9.5\text{ in.}}=+3{,}750\text{ lbs. per sq. in.}$$

This example has dealt with a hollow concrete column, but it is evident that the same process could be used to analyze the stresses in a reinforced concrete chimney.

Steel Beam Strengthened by Reinforced Concrete

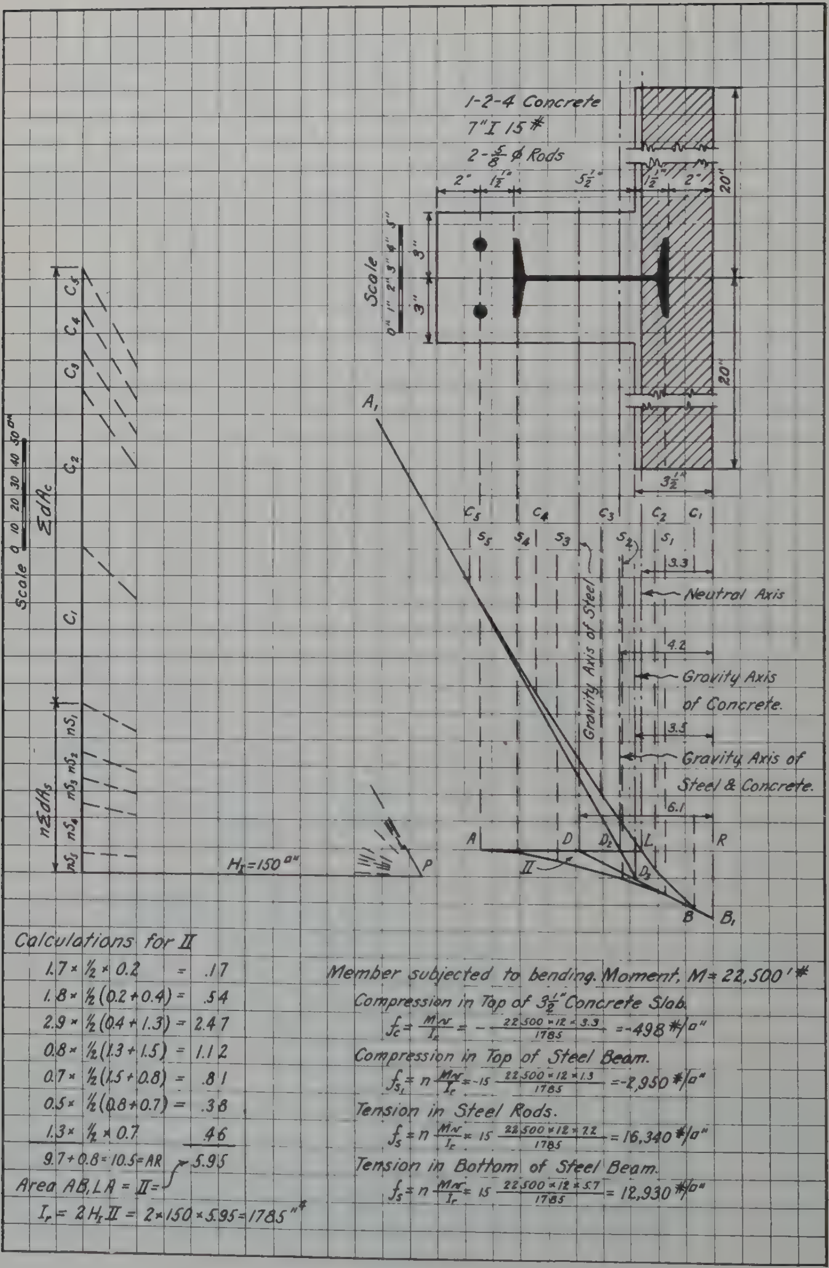
An example is given in Fig. 3 of a composite member subjected only to bending. Where only bending exists in a member the thrust is located at an infinite distance from the gravity axis of the section. But, as previously pointed out, the stress in a member can be determined by this method for any position of thrust. In this case e is equal to infinity. The value of Z is zero, and the E–E' curve is not needed.

The member under consideration is made up of reinforced concrete and structural steel. This combination was due to the necessity of strengthening some structural steel beams which were erected with the idea of supporting only a wooden roof. It was then decided to make the building a fireproof structure and a concrete roof was desired. The steel beams were found to be somewhat weak to support the heavier construction. To strengthen these beams and at the same time fireproof them concrete was cast around them. The concrete was reinforced to resist bending, and mechanical means were employed to make the structural steel and the reinforced concrete act together when the member was loaded.

The structural steel beam used was a 7-inch 15-pound "I." The concrete was 1: 2: 4. The forms for the concrete were supported in such a manner as to bring no load on the structural steel until the concrete had hardened and was able to take its share of the load. The reinforcing consisted of two bars of ⅝-inch diameter placed 1½ inches below the steel beam.

The value of n is taken as 15. A portion of the concrete slab equal to one-quarter of its span is considered as forming the top flange of the concrete "T"-beam.

The composite member is designed to resist a moment of 22,500 foot pounds. If this moment were resisted by the structural steel alone it would have produced a maximum fiber stress of 26,000 pounds per square inch.



Calculations for II

$1.7 \times \tfrac{1}{2} \times 0.2 = .17$

$1.8 \times \tfrac{1}{2}(0.2+0.4) = .54$

$2.9 \times \tfrac{1}{2}(0.4+1.3) = 2.47$

$0.8 \times \tfrac{1}{2}(1.3+1.5) = 1.12$

$0.7 \times \tfrac{1}{2}(1.5+0.8) = .81$

$0.5 \times \tfrac{1}{2}(0.8+0.7) = .38$

$1.3 \times \tfrac{1}{2} \times 0.7 \quad .46$

$9.7+0.8=10.5=AR \quad 5.95$

Area $AB_1LA = II =$ 5.95

$I_r = 2H_1 II = 2 \times 150 \times 5.95 = 1785''^4$

Member subjected to bending. Moment, $M = 22{,}500'\#$

Compression in Top of 3½" Concrete Slab.

$$f_c = \frac{Mv}{I_r} = -\frac{22500 \times 12 \times 3.3}{1785} = -498\#/\square''$$

Compression in Top of Steel Beam.

$$f_{s_1} = n\frac{Mv}{I_r} = -15\,\frac{22500 \times 12 \times 1.3}{1785} = -2{,}950\#/\square''$$

Tension in Steel Rods.

$$f_s = n\frac{Mv}{I_r} = 15\,\frac{22500 \times 12 \times 7.2}{1785} = 16{,}340\#/\square''$$

Tension in Bottom of Steel Beam.

$$f_s = n\frac{Mv}{I_r} = 15\,\frac{22500 \times 12 \times 5.7}{1785} = 12{,}930\#/\square''$$

FIG. 3.—COMPOSITE STEEL AND CONCRETE BEAM

The neutral axis of the cross-section is determined, for bending alone, in a manner similar to that already described.

The value of I_r is found from equation (12). It is seen from Fig. 1 that the area $LKGML$ represented by V becomes zero when Z equals zero, therefore —

$$I_r = 2\,H_I II = 2\,H_I\ (\text{area } ALB_1BA)$$

Stresses in the composite member are found from the familiar formula derived from the common theory of flexure.

$$f = \frac{Mv}{I_r}$$

The compressive stress in the concrete in the extreme fiber at the right-hand side of the cross-section (top of slab) is equal to

$$f_c = -\frac{Mv}{I_r} = -\frac{22{,}500 \text{ ft. lbs.} \times 12 \times 3.3 \text{ in.}}{1{,}785 \text{ in.}^4} = -498 \text{ lbs. per sq. in.}$$

The compressive stress in the extreme fiber at the right-hand side (top) of the structural steel beam is equal to —

$$f_{s_1} = -n\frac{Mv}{I_r} = -15\frac{22{,}500 \text{ ft. lbs.} \times 12 \times 1.3 \text{ in.}}{1{,}785 \text{ in.}^4}$$

$$= -2{,}950 \text{ lbs. per sq. in.}$$

The tensile stress in the steel reinforcing at the left-hand side of the cross-section is equal to

$$f_s = n\frac{Mv}{I_r} = 15\frac{22{,}500 \text{ ft. lbs.} \times 12 \times 7.2 \text{ in.}}{1{,}785 \text{ in.}^4}$$

$$= 16{,}340 \text{ lbs. per sq. in.}$$

The tensile stress in the extreme fiber at the left-hand side (bottom) of the structural steel beam is equal to

$$f_s = n\frac{Mv}{I_r} = 15\frac{22{,}500 \text{ ft. lbs.} \times 12 \times 5.7 \text{ in.}}{1{,}785 \text{ in.}^4}$$

$$= 12{,}930 \text{ lbs. per sq. in.}$$

APPENDIX

Graphical Determination of the Statical Moment and the Moment of Inertia of a Surface

Let *LMNRL* in Fig. 4*a* represent any surface. Let *XX* and *YY* be any rectangular co-ordinate axes passing through this surface and intersecting each other at the point *O*. The *XX* axis cuts the outline of the surface at the points *L* and *N*. The *YY* axis cuts the surface at the points *M* and *R*. The horizontal intercept *O–N* of the *XX* axis is divided into a number of equal parts. Let $\triangle x$ represent the width of each division, and C_1, C_2, etc., represent the middle ordinates of these divisions. If the divisions are taken sufficiently small the ratio between the areas is equal to the ratio between their respective intercepts. The intercepts thus being proportional to respective areas they may be used to represent the areas. If instead of a geometrical surface we had assumed a flat homogeneous solid of the same outline and of uniform thickness, C_1, C_2, etc., would represent the weights of the divisions. Whether the intercepts represent the areas or weights they may be treated in the following as weights, or forces.

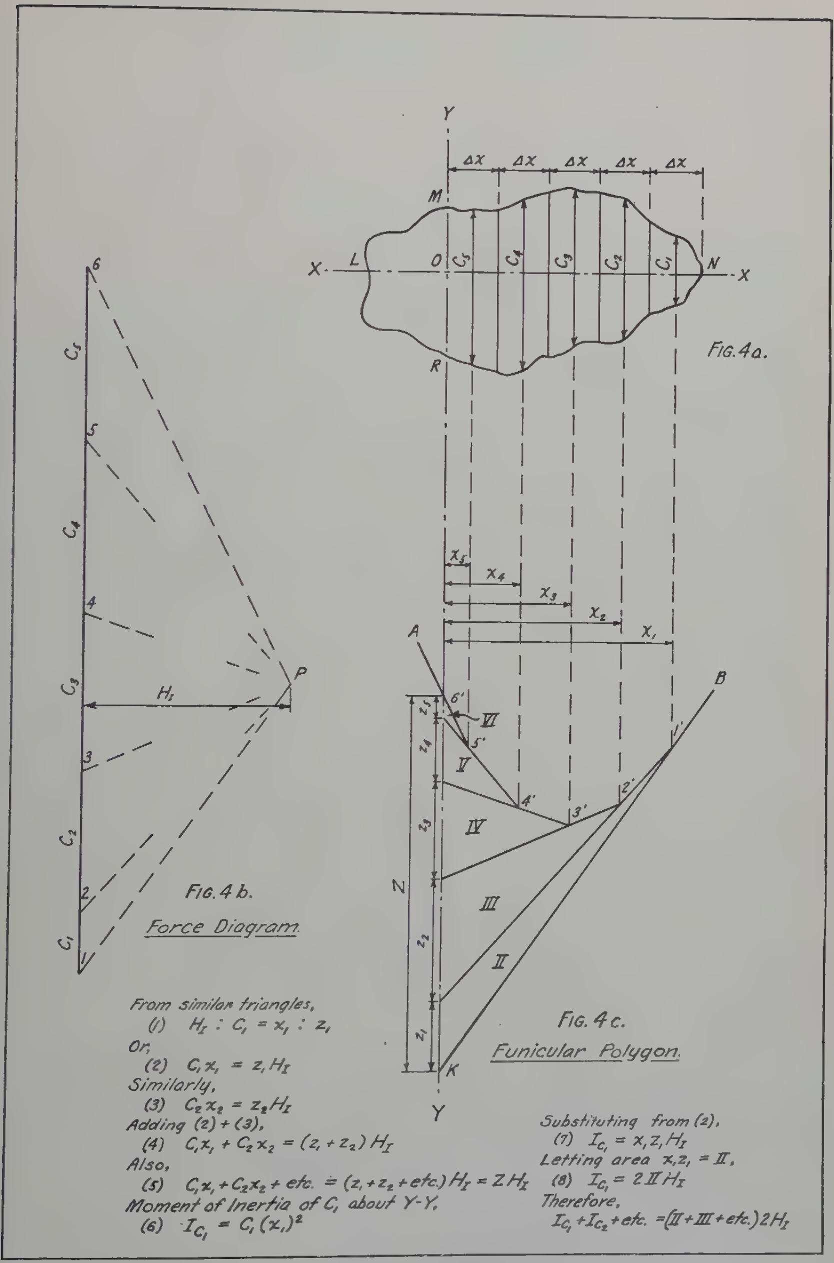
A force diagram is drawn in Fig. 4*b*. C_1, C_2, etc., are laid out in consecutive order and plotted to scale. A pole, *P*, is selected at a convenient distance, H_1, from the vertical load line, *1–6*. The rays *P–1*, *P–2*, etc., are drawn.

A funicular polygon is drawn in Fig. 4*c*. The lines of action of C_1, C_2, etc., are produced from Fig. 4*a*. Let x_1, x_2, etc., represent the horizontal distances from the vertical axis *YY* to these lines of action respectively. Beginning at any point *B*, at the right of the line of action of C_1, the string *B–1′* is drawn parallel to the ray *P–1* and intersects the C_1 line of action at the point *1′*. The string *1′–2′* is drawn parallel to the ray *P–2* and intersects the C_2 line of action at the point *2′*. In a similar manner the remaining strings of the funicular polygon are drawn. The string *5′–6′* intersects the vertical axis *YY* at the point *6′*. The string is produced to an indefinite point, *A*. The string *B–1′* produced cuts the *YY* axis at the point *K*. Each string is produced until it cuts the *YY* axis. Let z_1 be the intercept between the string *B–1′* produced and the string *1′-2′* produced. Let z_2, z_3, etc., be intercepts obtained in a similar manner. The sum of these intercepts is equal to *K–6′*, which is denoted by *Z*.

From similar triangles it is seen that —

$$(1) \qquad H_1 : C_1 = x_1 : z_1; \text{ or}$$

$$(2) \qquad C_1 x_1 = z_1 H_1$$



From similar triangles,
(1) $H_I : C_1 = x_1 : z_1$
Or,
(2) $C_1 x_1 = z_1 H_I$
Similarly,
(3) $C_2 x_2 = z_2 H_I$
Adding (2) + (3),
(4) $C_1 x_1 + C_2 x_2 = (z_1 + z_2) H_I$
Also,
(5) $C_1 x_1 + C_2 x_2 + \text{etc.} \doteq (z_1 + z_2 + \text{etc.}) H_I = Z H_I$
Moment of Inertia of C_1 about Y-Y,
(6) $I_{C_1} = C_1 (x_1)^2$

Substituting from (2),
(7) $I_{C_1} = x_1 z_1 H_I$
Letting area $x_1 z_1 = II$,
(8) $I_{C_1} = 2\,II\,H_I$
Therefore,
$I_{C_1} + I_{C_2} + \text{etc.} = (II + III + \text{etc.})\,2H_I$

FIG. 4.—APPENDIX

but C_1x_1 is the statical moment of C_1 about the YY axis and is thus equal to the z_1 intercept multiplied by the pole distance H_I.

In a similar manner it can be shown that —

$$(3) \qquad C_2x_2 = z_2H_I$$

Adding equations (2) and (3), we have —

$$(4) \qquad C_1x_1 + C_2x_2 = (z_1 + z_2)H_I$$

It is also evident that —

$$(5) \qquad C_1x_1 + C_2x_2 + \text{etc.} = (z_1 + z_2 + \text{etc.})H_I = ZH_I$$

but as C_1x_1, C_2x_2, etc., are equal to the statical moments of the small areas into which the area *OMNRO* is divided, their sum represents the statical moment of this total area to the right of, and about, the YY axis, and is equal to the total intercept, Z, times the pole distance, H_I. As YY represents any vertical axis passing through the surface, any vertical intercept between the funicular polygon A–B and the string B–$1'$ produced, multiplied by the pole distance H_I, is equal to the statical moment of the area to the right of, and about, the line of interception. In a similar manner, any vertical intercept between the funicular polygon A–B and the string A–$5'$ produced, multiplied by the pole distance H_I, is equal to the statical moment of the area to the right of, and about, the line of interception.

The same method of determining the statical moment of a surface applies when the axis lies entirely outside the surface.

Let the moment of inertia, about the YY axis, of the area represented by C_1 be equal to I_{C_1}, and the moments of inertia of the areas represented by C_2, C_3, etc., be equal respectively to I_{C_2}, I_{C_3}, etc.

$$(6) \qquad I_{C_1} = C_1(x_1)^2$$

Substituting the value of C_1x_1 from equation (2) —

$$(7) \qquad I_{C_1} = x_1z_1H_I$$

but x_1z_1 is equal to twice the area of the triangle, having z_1 as a base and x_1 as an altitude. And if we let the Roman numerals *II*, *III*, etc., represent the areas of the triangles having respectively z_1, z_2, etc., for bases and x_1, x_2, etc., for altitudes, the following equation may be written:

$$(8) \qquad I_{C_1} = 2\,II\,H_I$$

In a similar manner it can be shown that —

$$(9) \qquad I_{C_2} = 2\,III\,H_I$$

adding equations (8) and (9) —

$$(10) \qquad I_{C_1}+I_{C_2}=(II+III)2\,H_I$$

It is also evident that

$$(11) \qquad I_{C_1}+I_{C_2}+\text{etc.}=(II+III+\text{etc.})2\,H_I$$

But as I_{C_1}, I_{C_2}, etc., are equal to the moments of inertia of the small areas into which the area *OMNRO* is divided, their sum represents the moment of inertia of this total area to the right of, and about, the *YY* axis, and is equal to twice the sum of the areas $(II+III+\text{etc.})$ times the pole distance. In a similar manner the moment of inertia of the area to the left of, and about, the *YY* axis is found. The moment of inertia of the total surface about this axis is equal to the sum of the moments of inertia of the portions of the surface to the right and left of the axis.

The same method of determining the moment of inertia of a surface applies when the axis lies entirely outside of the surface.

OF GENERAL INTEREST

CONSTRUCTION ACTIVITIES ON BOSTON & MAINE RAILROAD

New Office Building under Construction at Lechmere Square —Coal Handling Facilities at Mystic Wharf to be Modernized

Various construction projects are underway on the Boston & Maine Railroad; included among them are a new office building and a modernization of coal-handling facilities. It is believed that certain of the details of these will be of interest to our readers. Mr. Frank C. Shepherd, Chief Construction Engineer, Boston & Maine Railroad, has furnished the information on which this article is based.

NEW OFFICE BUILDING

The Boston & Maine Railroad started work in August, 1925, on a new General Office Building at Lechmere Square, East Cambridge, this building being opposite the Boston Elevated Railway Terminal and facing on the northerly side of the new Northern Traffic Artery.

This eight-story building, 50 by 305 feet, is to house all the general offices of the Boston & Maine Railroad which are now located in the present North Station, the old Fitchburg Station, the so-called Bent Building on the corner of Causeway and Portland Streets, and in several other places on the Terminal.

The building is of the modern factory type, reinforced-concrete construction, built with special lighting arrangements. It is of beam and slab construction with one central line of columns spaced 24 feet apart so that the walls have 4-foot pilasters in each bay and 20-foot reversible type Fenestra steel-sash windows extending from window sill to ceiling.

Due to length of building a fire wall has been carried up in the center, making two distinct units, each unit having at either end, on the back, enclosed stairways and two toilet rooms. Two elevators are to be installed on one side of the fire wall and arrangements have been made for future installation of two more on the other side. Steam boilers for heating have been installed in a large boiler room in the basement, this room also including hot-water heater. Coal is brought to the rear of the building on a side track and dumped directly from the car into hopper leading to the boiler room. Arrangements have also been made for hoisting cinders and ashes from boiler room and dumping them into the empty cars for removal.

A modern air-conditioning plant is being installed with two separate units, furnishing fresh air and removing foul air on either side of the fire wall.

In the basement a modern cafeteria, with seating capacity of approximately 375, is being installed in the easterly half, this being reached at either end by stairways.

No particular difficulties were encountered in the foundations, the borings developing good bearing sand at a depth of 12 to 18 feet from the sidewalk.

The excavation and foundation work was done by T. Stuart & Son Company. The building is being erected by the Scully Company, the heating installation by Ingalls & Kendricken, Inc., the electric light installation by the Lord Electric Company, the elevators furnished by the Bay State Elevator Company and the air-conditioning plant by the B. F. Sturtevant Company.

Although the building will not be entirely completed until about April first, work has progressed so far that it is planned to have the first five floors ready for occupation by the Accounting Department in February. The general movement of the other offices will probably take place early in April.

Coal-handling Facilities

The Boston & Maine Railroad has recently made a contract with John H. Proctor & Co. of Boston for the modernization of its coal-handling facilities at Mystic Wharf, for which an expenditure of approximately $500,000 will be made, the new installation to include three unloading towers and a six-ton coal stocking and reclaiming bridge.

For unloading coal from the boats the contract provides for the installation of three steam-operated unloading towers of steel construction, these towers to travel on the tracks now used by the present towers. Each tower is to have a maximum capacity of unloading mine-run bituminous coal from boats or barges at the rate of 400 net tons per hour, and the towers are so arranged that coal can be loaded out into railroad cars on either of two tracks under the towers or transferred into a cushion pile back of the towers by means of a belt-conveyor stacker.

A hopper of 60 net tons' capacity will be built into each tower. Beneath the hopper there will be two steam-operated gates and adjustable chutes for loading coal into cars. Beneath the hopper there will also be a belt conveyor of 400 tons per hour capacity for use in transferring coal to the cushion pile back of the towers, the center of the pile being approximately 100 feet from the edge of the wharf and providing capacity of approximately 20 tons per linear foot of cushion pile.

The handling of coal from the cushion pile is provided for through the installation of a six-ton coal stocking and reclaiming bridge of 315-foot span which will transfer coal from the cushion pile beneath its cantilever to the main storage pile beneath the span, and reclaim the coal by transferring from the storage pile to either of two hoppers, one for loading out into railroad cars and the other for loading a future pocket which is provided for in case it should be found advisable to load coal into trucks.

This bridge will have a maximum capacity of transferring mine-run bituminous coal from the center of the cushion pile, beneath the cantilever, to the center of the main storage pile at the rate of 700 net tons per hour, or from the center of the main storage pile by either of the hoppers at a maximum rate of 600 net tons per hour.

A hopper of 60 net tons' capacity will be located at the Shear Leg of the bridge, this hopper being provided with steam-operated gate and adjustable chutes for the purpose of loading cars which will be located on two tracks

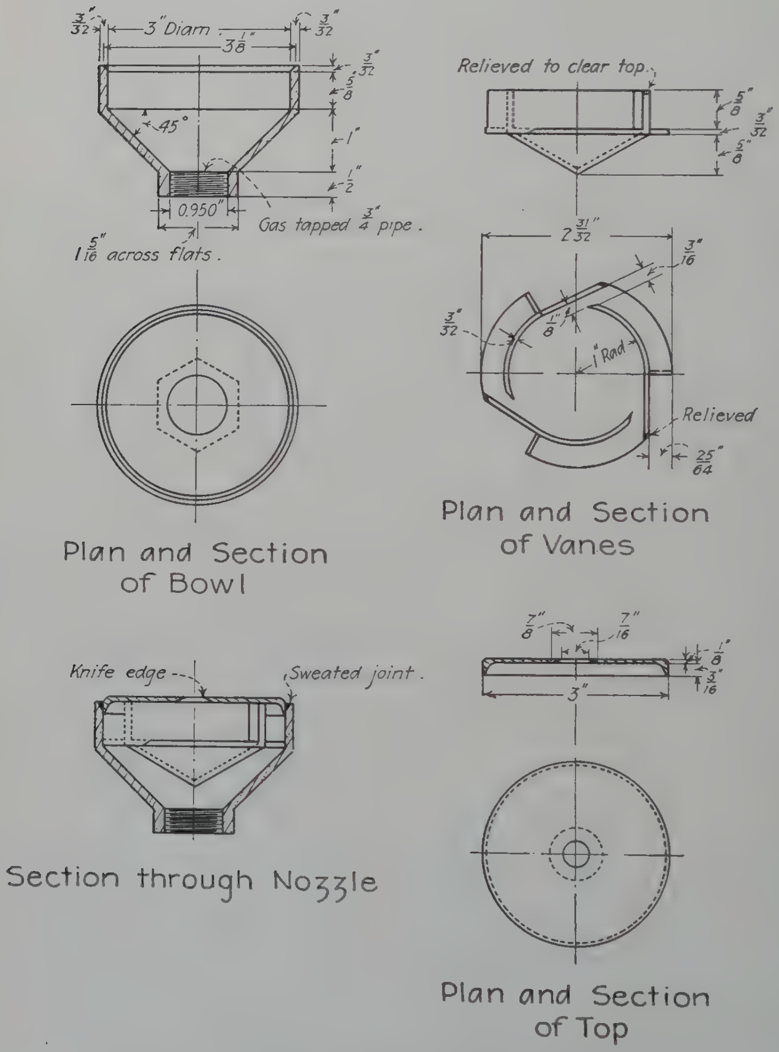


FIG. 1.—TRIPLE ENTRY AERATOR NOZZLE

beneath the hopper and either side of the Shear Leg, the plan providing for two tracks, one either side of the Shear Leg. At this point there will also be provided a deflecting hopper for the purpose of loading into a future pocket when same may be provided in case coal should be handled by trucks.

At the present time coal is unloaded from the boats by 8 towers, 5 of wood and 3 of steel construction, with 1¼ ton buckets, these towers traveling on tracks approximately 23 feet on centers and paralleling the wharf along the water front, the total length of wharf frontage being approximately 2,000 feet.

These towers have a combined average capacity of approximately 4,800 tons per day, the average annual unloading in recent years being approximately 1,400,000 net tons.

From the towers the coal is loaded directly into cars, one track passing under the tower and one track outside and on the back of the tower from the edge of the wharf.

For storage there was originally a cableway some 3,800 feet long, constructed so that surplus coal from the towers was loaded into cars on the cableway and then dumped on the ground under the cableway, with a storage capacity of approximately 60,000 tons, which could be increased to 90,000 tons by rehandling. Reloading of the coal was accomplished with steam shovel or locomotive crane with clam-shell bucket, loading coal into cars.

Due to the condition of this cableway and the high cost of its operation, its use was discontinued a few years ago, and since that time coal has been stored on railroad land along Middlesex and Mystic avenues, coal being unloaded from cars to the ground by locomotive crane and reloaded by the same method.

New Sewage Sprinkler Nozzle

Under the direction of Mr. A. Gordon Gutteridge, Chief Engineer, Department of Health, Commonwealth of Australia, a new sewage sprinkler nozzle has been developed which is giving good service at the Ballarat Sewage Treatment Works. This nozzle, the construction of which is illustrated in Fig. 1, differs from the nozzles commonly in use in the following essentials: (1) It is designed to operate under a constant head. (2) It operates continuously. (3) It distributes within narrow limits an equal quantity of sewage over unit areas during the same intervals of time. Under these conditions of operation the nozzle does

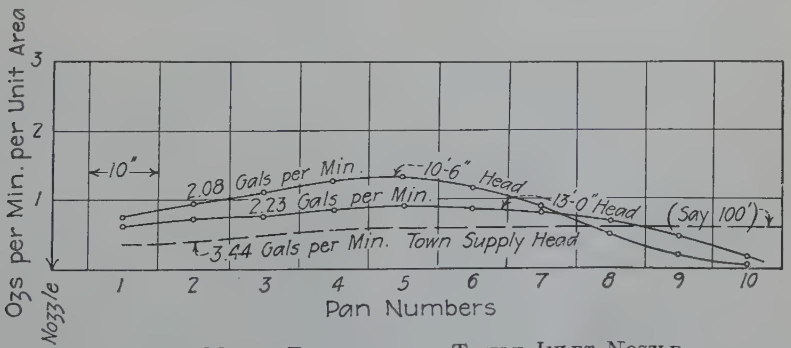


FIG. 2.—MODEL EXPERIMENTAL TRIPLE INLET NOZZLE

3″×1$\frac{1}{16}$″×$\frac{1}{8}$″=0.258 sq. in. entry. Distribution with 10′6″, 13′0″ and 100′ (approx.) heads not require the use of dosing tanks or other regulating devices. A test of this nozzle under different heads is recorded graphically in Fig. 2. The nozzle spacing adopted at Ballarat is 10 feet.

Water Supply Data

Hydraulic engineers having problems in water power, water supply or valuations of hydraulic structures may be interested to know that "Water-Supply Paper 561", a 300-page report containing records of stream flow and discharge measurements for rivers in the North Atlantic Coast drainage basins for the year ending September 30, 1923, has recently been issued by the United States Geological Survey. This report contains data collected at 135 stations, 67 of which are in New England, distributed as follows:

Maine, 24 stations; New Hampshire, 14; Vermont, 4; Massachusetts, 21; Connecticut, 3; Rhode Island, 1; New York, 28; New Jersey, 34; Maryland, 3; Virginia, 2; West Virginia, 1.

A considerable number of the records were furnished for publication, the field data having been collected by engineers not connected with the Geological Survey, for which credit is given in the descriptions of the stations.

In addition to the table of contents and four-page index of the data in this report, there is a reference list of "Stream Gaging Stations and Publications relating to Water Resources" which contains the names and locations of all gaging stations in the North Atlantic Coast drainage basins for which records have ever been published by the Geological Survey, together with a table giving the serial numbers of the Water-Supply Papers which contain records for the years 1899 to 1923. Miscellaneous reports, State reports, geologic folios, bulletins, and professional papers relating to the North Atlantic States are listed, with brief descriptions of contents.

Editions of United States Geological Survey Water-Supply Papers are now limited to a few hundred copies on account of shortage of funds, and few copies are available for free distribution. Those desiring copies of No. 561 can obtain them from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 35 cents each, and the report may be consulted in the library of the Affiliated Technical Societies of Boston, 715 Tremont Temple, Boston, Mass.

Stream Gaging in Massachusetts

The Division of Waterways and Public Lands, Massachusetts Department of Public Works, has recently received a copy of the report of the United States Geological Survey giving results of the stream-gaging work in Massachusetts for the year ending September 30, 1925.

This report contains tables arranged in the customary form, showing daily and monthly discharge for each of the nineteen gaging stations; the tables also show maximum, minimum and mean daily discharge for each month, together with run-off in second-feet per square mile and depth in inches. The station description gives for each station certain information regarding the location of the gage and the method of obtaining the records; also a statement under "Extremes of discharge" for the absolute maximum and minimum stage for the year.

This report is kept on file in the Division of Waterways and Public Lands, State House, Boston, and may be consulted at any time by those who are interested in such figures, or a copy may be seen at the office of the United States Geological Survey, Custom House, Boston.

Zoning Progress

Since the issuance of the January, 1925, Zoning Progress Report the names of over a hundred additional municipalities in the United States have been reported to the Division of Building and Housing of the United States Department of Commerce.

Twenty-two of the cities and towns recently adopting zoning are in Massachusetts, showing plainly the present-day trend in civic activities in this State. In most cases the zoning ordinances have been comprehensive, regulating "use," "height" and "area" of buildings.

Researches in Concrete

A very interesting bulletin of Purdue University by Prof. W. K. Hatt on "Researches on Concrete," No. 24, has recently been issued. Members desiring a copy of this report can obtain it upon application to W. E. Hatt, Manager, Structural Bureau, Portland Cement Association, Conway Building, Chicago.

PROCEEDINGS OF THE SOCIETY

MINUTES OF MEETINGS

Boston Society of Civil Engineers

January 27, 1926. — A regular meeting of the Boston Society of Civil Engineers was held this evening in Chipman Hall, Tremont Temple, and was called to order by the Vice-President, Charles B. Breed, at 7.30 P.M. There were about 100 members and guests present.

The minutes of the previous meeting (November 18, 1925) were approved as printed in the December Journal.

The Secretary announced the names of those elected to membership by the Board of Government at its December and January meetings.

December 23, 1925. *Members:* Robert Gillespie, Albert E. Kleinert, Jr., Reginald B. Miner. *Juniors:* Frederick Mellor, Irving Traverse, Stanley Szlanda.

January 27, 1926. *Members:* Miles N. Clair, Mortimer M. Gibbons, John F. Hennessy, Henry D. Johnson,* Theodore B. Parker, William T. Thompson. *Juniors:* Alphonse A. Chernesky, Leland C. Fitts, Christos Harmantas, Philip P. Pasqualino.

The Chairman announced that Ralph D. Hood, a member of the Society since March 15, 1916, had died on January 9, 1926, and that a committee would be appointed to prepare a memoir.

Professor Breed then stated that this was a joint meeting of the Boston Society of Civil Engineers and the Sanitary Section of the Society, and he introduced E. Sherman Chase, Chairman of the Sanitary Section, who presided during the remainder of the program.

After speaking briefly of the activities of the Rockefeller Foundation, Mr. Chase introduced Dr. George E. Vincent, President of the Rockefeller Foundation, who gave an address on "The Engineer and Public Health."

Dr. Vincent gave a most interesting address, which was broadcast by Station WSSH, Tremont Temple, Boston. Following the address Dr. Vincent answered a number of questions.

The meeting adjourned at 8.40 P.M. after giving a vote of thanks to Dr. Vincent for his courtesy in coming to Boston and giving such a splendid talk.

J. B. Babcock, *Secretary.*

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* Transferred from grade of Junior.

Designers Section

January 12, 1926. — The regular January meeting of the Designers Section of the Boston Society of Civil Engineers was called to order at 6.17 p.m. in the Affiliation Rooms, 715 Tremont Temple, Boston.

The minutes of the December meeting were read and approved. The chairman then introduced Mr. B. A. Rich and Mr. W. W. Bigelow of Rich, Bigelow & Tirrell, who spoke on "Stresses in a Composite Member subjected to Bending and Direct Stresses."

This talk was followed by one on "The Effect of 'Cal' on Cement and Concrete" by Mr. M. N. Clair of The Thompson & Lichtner Company.

There were 65 members and visitors present. The meeting adjourned at 7.55 p.m.

Scott Keith, *Clerk.*

APPLICATIONS FOR MEMBERSHIP

[February 15, 1926]

The By-Laws provide that the Board of Government shall consider applications for membership with reference to the eligibility of each candidate for admission and shall determine the proper grade of membership to which he is entitled.

The Board must depend largely upon the members of the Society for the information which will enable it to arrive at a just conclusion. Every member is therefore urged to communicate promptly any facts in relation to the personal character or professional reputation and experience of the candidates which will assist the Board in its consideration. Communications relating to applicants are considered by the Board as strictly confidential.

The fact that applicants give the names of certain members as reference does not necessarily mean that such members endorse the candidate.

The Board of Government will not consider applications until the expiration of twenty (20) days from the date given.

For Admission

Berry, James Francis, Boston, Mass. (Age 21, b. Boston, Mass.) Graduate of Mechanic Arts High School. Has worked for Barnes & Beal, Waltham; town of Belmont, engineering department; Marden & Orlando Construction Company, Boston; C. R. Mosher, North Dartmouth; and is now a student at Northeastern University. Refers to H. B. Alvord, C. S. Ell, J. W. Ingalls, W. E. Nightingale.

Brockway, Warner Cotton, Melrose, Mass. (Age 30, b. Hartstown, Pa.) Graduate of University of Michigan. February, 1918, to December, 1919, in U. S. Army, Engineering Division, Sanitary Corps; January 1, 1920, to March, 1922, assistant engineer, Michigan Department of Health; March, 1922, to October, 1923, engineer, Taxpayers League of St. Louis County, Duluth (municipal research work); October, 1923, to date, with the Philip Carey Company, manager, Asbestos Roofing and Shingle Department. Refers to A. H. Blanchard, G. G. Dixon, Edward Wright.

Cochrane, Earle Seymour, Cambridge, Mass. (Age 21, b. Cambridge, Mass.) Student at Northeastern University. During work periods has been employed by Whitman & Howard, Inc., from February, 1923, to September, 1925. At present is with the Massachusetts Department of Public Works, Highway Division. Refers to H. B. Alvord, F. V. Britt, C. S. Ell, Erwin Harsch, J. W. Ingalls, W. E. Nightingale.

Hamparian, Hampar B., Boston, Mass. (Age 23, b. Harpout, Armenia.) Has worked with the following for two years as rodman and instrumentman: C. H. Gannett and Metropolitan District Commission, Park Division. Now a student at Northeastern University. Refers to H. B. Alvord, Maurice Bloom, A. E. Harding, J. W. Ingalls, W. E. Nightingale.

Stiles, Ransom Wentworth, Forest Hills, Mass. (Age 19, b. Roxbury, Mass.) Educated Roxbury High and Mechanic Arts High School. May, 1923, to June, 1924, worked with New York, New Haven & Hartford Railroad, as head chainman; September, 1924, to March, 1925, with Metropolitan District Commission, Sewerage Division, as draftsman; March, 1925, to December, 1925, with Massachusetts Department of Public Works, Highway Division, as senior engineering assistant and draftsman; December, 1925, to date, draftsman in City Department of Public Works, Sewer Service. Refers to G. C. Barry, W. W. Davis, E. S. Dorr, C. S. Drake, F. A. Lovejoy, J. A. Rourke.

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THEODORE B. PARKER, Wellesley Farms, Mass.

Juniors

CHRISTOS HARMANTAS, 177 Franklin Street, Cambridge, Mass.

OSCAR R. LINDGREN, 25 Clarkson Street, Ansonia, Conn.

STANLEY SZLANDA, 58 Hargraves Street, Fall River, Mass.

DEATHS

RALPH D. HOOD . .	January 9, 1926.
LEONARD METCALF .	January 29, 1926.

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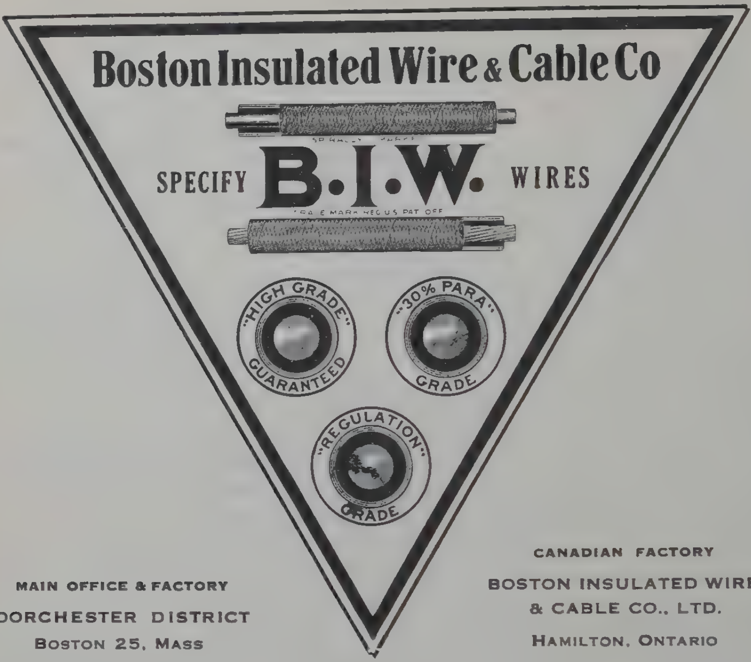

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